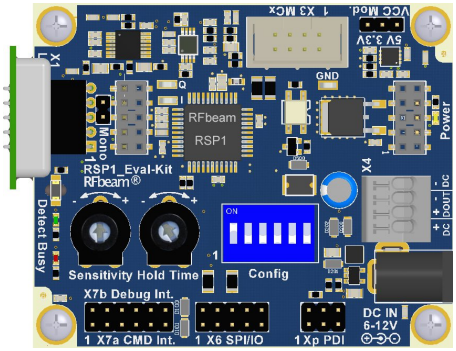
RSP1 Evaluation Kit

User Manual

Features

- Reference design for RFbeam RSP1 processor
- Advanced movement detection system
- High performance signal processing
- More detection range than traditional designs
- Less susceptibility to interferences
- Supports most RFbeam Radar transceivers
- Stand alone or host operated modes
- Analyzing and command software tools included
- Saves time to market and development investments



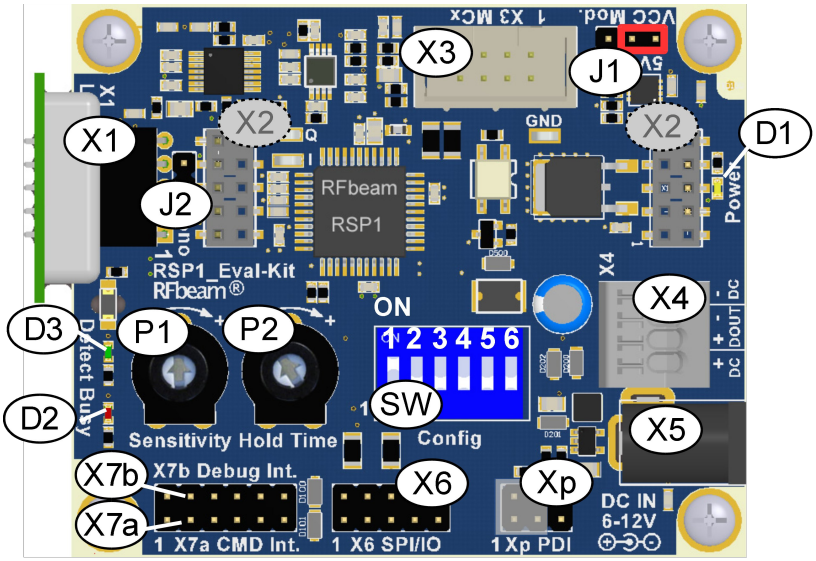
Applications

- Reference design for own developments based on RSP1 processor
- Exploring FFT based Dopppler signal processing
- Optimizing choice of sensor type for different applications

Overview

RSP1 Evaluation Kit is a fully operational movement sensor application using advanced signal processing. It saves an important amount of evaluation and development time and money.
The RSP1 processor offers adaptive noise cancelling and automatic adaptation to different Doppler transceivers.

Functionality can be influenced by manual settings as well as by more than 30 parameters and commands.
The kit can be used as stand alone system or as a server of a host computer or microcontroller.
The kit contains helpful software tools for configuration and signal visualization.



Indicators	
D1	Power LED
D2	Busy LED (start-up)
D3	Detection LED
Connectors	
X1	K-LCx sensor connector
X2	***Backside*** K-LCx connector
X3	K-MCx sensor connector
X4	Digital output connector
X5	DC Supply input 6 .. 12V
X6	Digital I/O (SPI in preparation)
X7a	Serial Command (**RSP_Terminal**)
X7b	Serial Debug (**RSP_Scope**)
Xp	Reserved / Reset
Settings	
P1	Sensitivity pot
P2	Hold time pot
SW	Mode switch
J1	Sensor supply volage
J2	Optional for mono sensor

Fig. 1: Connectors and indicators

Packing List

1. Eval-Kit PCB board
2. RS232 USB cable
3. USB stick containig
   - RSP_Terminal software, RSP_Scope software, FTDI USB-Serial drivers
   - Documentation
4. 5 different RFbeam Radar sensors:
   - K-LC1a, K-LC3 (1 channel sensors, also called "mono sensors")
   - K-LC2, K-LC5, K-LC6 (2 channel sensors, also called "stereo sensors", "I/Q sensors")

Getting Started

Preparation

We will begin with using the Evaluation Kit as stand-alone device without any PC software.

Please follow step by step:

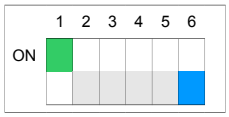
1. Install software from USB stick by starting "setup.cmd"
   Different software modules will be installed. If your computer does not already contain the actual LabVIEW runtime engine, you will be asked to accept licenses of National Instruments. Please accept all default storage locations. Several installers are executed by a script. Accept installers until the end of complete installation.

2. If correctly installed, You will find RSP_Terminal and RSP_Scope software under START-PROGRAMS-RFbeam-RSP and the program Icons on your desktop

3. Connect the FTDI USB cable to PC. Leave RSP side connector unplugged!
   FTDI Hardware should be recognized by Windows after some seconds.
   Unplug USB cable from PC again so that power of the kit is off

4. Insert the **K-LC2** sensor in RSP_Evaluation-Kit front connector X1

5. Set 'SW' DIP switch '1' in ON position, all other should be OFF:



6. Set Potentiometer P1 (sensitivity) to maximum (towards +)

7. Set Potentiometer P2 (hold time) to minimum (towards -)

Always unplug power supply befor inserting or unplugging sensors

RFbeam K-LCx radar module are susceptible to electrical discharge . Before plugging the module, please touch first the RSP1 board and then insert the K-LCx device.

Quick Start

No PC software is required yet.

1. Plug in USB cable into X7a (**black wire must be connect to pin '1'**)
2. Plug in USB cable into a USB port of your PC or notebook. This serves as power supply now.
3. Look at the LED indicators
   - D1 power LED is on
   - D2 busy LED turns on for about 5 seconds: RSP1 is learning the sensor and environment.
4. RSP1 is ready, as soon as red D2 is off

RSP1_Eval-Kit can also be used without a PC and USB cable. Use a 12VDC adapter or a 9V battery connected to the X5 power supply connector instead.

Explore!

You have plugged in a K-LC2 "I/Q stereo" sensor. This allows distinguishing between movements towards and backwards from the sensor. (This behavior can be changed by other DIP switch settings).

→ Forward movement;

- Green indicator LED3 turns on only, if there is a forward movement to the sensor. Walk around in some distance from the sensor and check this.

→ Sensitivity potentiometer:

- This affects the maximum detection distance. May be that there is no more reaction near the minimum sensitivity. This behavior depends on the sensor type.

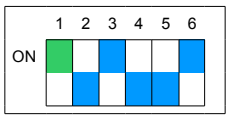
→ Hold time potentiometer.

- Turn it to the center position: hold time will be around 5 seconds. Maximum hold time is around 160 seconds.

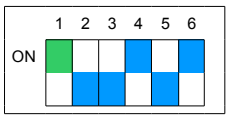
→ Direction settings;

- Set sensitivity to maximum and hold time to minimum again to get best experience.
- Set switches to explore detection modes:

"Mono":
detects movement in both directions



"Backwards":
detects movements away from the sensor only



→ Try other sensors and settings:
Refer to Switch Settings Summary.

Always unplug power supply befor inserting or unplugging sensors.

Do not try to connect any device on X2 component side!
Connector X2 is for connecting sensors on the backside of the Evaluation Kit only.

Switch Settings Summary

Settings and around 30 parameters can be set and permanently stored by an ASCII terminal connected via the command interface at X7a. Please refer to the RSP1 data sheet for more information.
For stand alone operation, most important parameters my be set by potentiometers and a DIP switch.

Mode Switch 'SW'

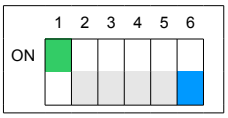
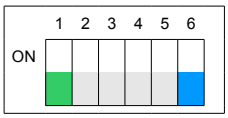
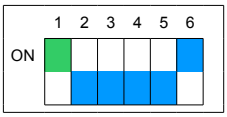
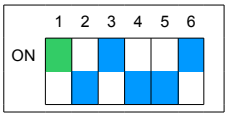
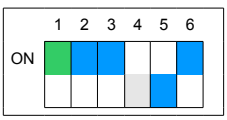
Changes becomes valid only after power up.

Switch #	Function	ON	OFF (default)
1	Sensitivity / Hold Time	Use potentiometers	Use EEPROM Sensitivity/Hold settings
Switches 2 … 5 take only effect, if switch #6 is in ON position			
2	Sensor type	Mono sensor (K-LC1 e.g.)	I/Q sensor (K-LC2 e.g.)
3	Direction mode	Mono (even with I/Q sensor)	Stereo (=Directional)
4	Direction	Backward	Forward
5	Immunity	Higher interference immunity	Low interference immunity
6	Select Setting mode	Use switch 2 … 5 settings	Use EEPROM Mode settings

Typical Settings

These examples assume standard default parameters in EEPROM. For more information on EEPROM parameters refer to the RSP1 datasheet.

Switch #1 defines, if potentiometers for sensitivity and hold time will be active or if fix values will be used.
Switch #6 enables settings of switches #2 .. #5.

Configuration	Switch Setting	Remarks
Use Potentiometers		All parameters from EERPOM except potentiometers. Defaults: - I/Q stereo sensor (K-LC2, K-LC5, …) - Direction forward
Manual settings inactive		All parameters from EERPOM. Defaults: - Maximum sensitivity - Minimum hold time - I/Q stereo sensor (K-LC2, K-LC5, …) - Direction forward
Manual settings active **Typical directional setting**		Most important parameters manually set: #2: I/Q stereo sensor (K-LC2, K-LC5, …) #3: Direction mode stereo #4: Direction forward #5: Standard interference immunity.
Manual settings active **Typical non directional setting with I/Q stereo sensor**		Most important parameters manually set: #2: I/Q stereo sensor (K-LC2, K-LC5, …) #3: Direction mode mono #4: Direction forward #5: Standard interference immunity.
Manual settings active **Typical non directional setting with mono sensor**		Most important parameters manually set: #2: Mono sensor (K-LC1, K-LC3) #3: Direction mode mono #4: Don't care #5: Standard interference immunity.

Using RSP Software Tools

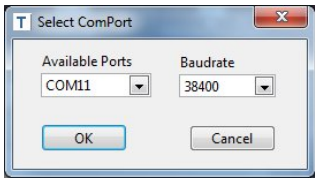
- RSP_Terminal software allows viewing and changing RSP parameters via serial interface on connector X7a. Optionally, it can also be used on connector X7b.
- RSP_Scope software allows viewing internal signals via serial interface on connector X7b.

Consult the RSP1 datasheet for more detailed explanations on signal processing

RSP1 tools use an FTDI cable virtual com port cable (TTL-232R-3V3) from www.ftdichip.com.
Drivers have been installed automatically together with the RSP1 tools installer.

Locating the Serial Port

Please connect the FTDI cable to a USB prot of your computer.
When starting an RSP1 tool, a com port dialog appears:



Normally, the highest COM port number is the right port.

To be sure, please unplug and replug the USB cable during this dialog. The related port number will disapear and apear again.

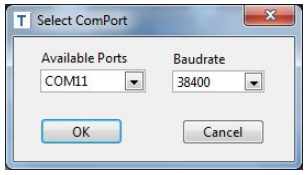
The RSP tools will remember the selected port.

Fig. 2: Connection Dialog

RSP_Terminal

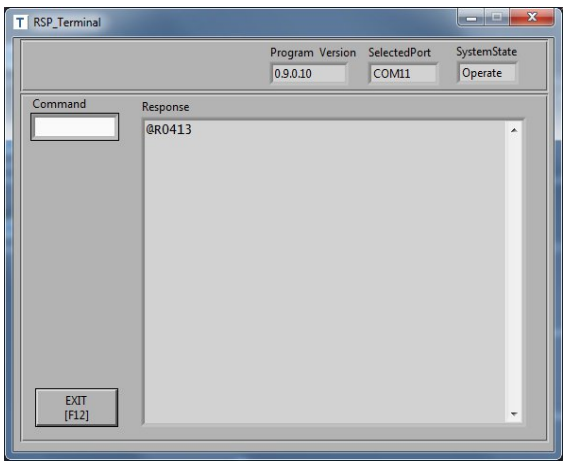
RSP1 processor can be influenced by many parameters. RSP_Terminal allows viewing and setting all parameters. In fact, RSP_Terminal emulates a host computer or microprocessor used in a RSP1 based user hardware.

Establish Connection



Establish connection:

1. Connect serial cable to Eval-Kit connector X7a
2. Connect serial cable to USB port of you PC
3. Start RSP_Terminal software
4. Select Port at **baudrate 38400**.
5. Press OK



Check if connection works:

Type command `$R04` ("get RSP1 version")
→ Example Response `@R0413` (Version 1.3)

Entering Commands

RSP1 follows a client-server protocol. RSP1 is the server that executes the client (Host/PC) commands.
Some rare exeptions exist when executing loop commands.
All parameters of classes 'A' and 'S' are stored in the permanent EEPROM memory.

Command Syntax

Read parameters: Command `$A02<ENTER>` → Response `@A0209`
Write parameters: Command `$A0203<ENTER>` → Response `@A0203`

Example **read** command	Explanation
`$A02<ENTER>`	$: command identifier A: command class 02: 2 digit hexadecimal parameter number Enter: Enter key (or <CR> or <CR><LF> code)
Example response	
`@A0209<CR><LF>`	@: response identifier A02: command confirmation 09: actual 2 digit value (typically hexadecimal) CRLF: codes for "carriage return-line feed"
Example **write** command	
`$A0203<ENTER>`	$: command identifier A: command class 02: 2 digit parameter number 03: 2 digit new parameter value (typically hexadecimal) Enter: Enter key (or <CR> or <CR><LF> code)
Example response	
`@A0203<CR><LF>`	@: response identifier A02: command confirmation 03: 2 digit value confirmation (typically hexadecimal) CRLF: codes for "carriage return-line feed"
Example **read** command	returns a string
`$R10`	Get firmware version string
Example response	
`@RFbeam RSP1 Version V1.4 Sep 19 2014`	String responses are marked in parameter table with *

You may repeat a command by simply typing $<ENTER>

Most important Parameters and Commands

For complete parameter list please refer to the RSP1 Data Sheet

Param.	default	min	max	Function	Description	R
Class A	(EEPROM)			**Application Parameters**	End-User specific settings in final application	
A01	01	00	09	hold time	9: maximum hold time of detection output	
A02	09	00	09	sensitivity	9: maximum detection sensitivity	
A03	03	00	09	immunity	9: maximum immunity against interference	
A05	00	00	02	direction	0: approaching; 1: receeding; 2: both	
Class S	(EEPROM)			**System Parameters**	Application specific parameters	
S00	00	00	01	sensor type	0: stereo I/Q sensor; 1: mono sensor (1 channel)	x
S01	00	00	01	Use alternate analog port	1: ADC input on pin 2 and 3 instead of pin 44 aqnd pin 1	x
S03	02	01	0A	sampling rate	see Fig. 11	x
S08	01	00	01	bandwidth	1: low bandwidth (digital output used for external filter)	
S09	04	00	04	ADC gain	gain = 2^n: 0 -->1; 1-->2; 2-->4; 3-->8; 4-->16	x
S0C	02	00	FF	Adaptive learn speed	0: maximum; >0: value * 500ms/dB	x
Class R	(immediate)			**Real-Time Read Params**	Read only parameters	
R00	-	00	01	detection active?	1: detection output active (includes hold time)	
R01	-	00	FF	detection speed	0: no peak position (FFT bin #)	
R02		0	FF	noise level mean	arithmetic mean over all FFT bins	
R04	-	00	FF	software version	major.minor version (x.0 are preliminary versions)	
R10	*	--	--	software version string	Full software version and date string, max 40 characters	
R11	*	--	--	result string on serial cmd port	SpeedFW, SpeedBW, MagFW, MagBW<CR>	
Class W	(immediate)			**Real Time Write Params**	Volatile write parameters	
W00	-	00	01	force detection output	1: set digital detection output; 0: normal output operaton	
W01	**-**	**-**	**-**	reset processor	software reset. value has no effect	
W02	**-**	**-**	**-**	**load default parameters**	**load default values for all parameters**	
Class L	(LOOP)			**Continuous output**	Output results continuously until $<CR> is received	
L00	-	-	-	result string on serial cmd port	SpeedFW, SpeedBW, MagFW, MagBW<CR>	

Note: Column “R”: Reset required

Restore original default parameter values with command ***$W02***

Repeat a command by simply typing $<ENTER>

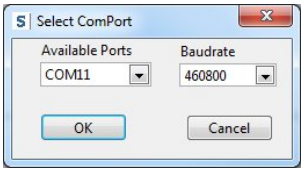
RSP_Scope

This tool is a virtual oscilloscope and shows internal amplitude vs. speed signals. It also shows I and Q time domain signals.
All signals including FFT are processed by RSP1 chip and are sent via high speed serial interface.
RSP_Scope does only scale some values, but does no signal processing.

- RSP_Scope must be connected to connector X7b at 460800 Baud.
- All explanations assume a K-LC2 sensor and RSP default parameters.

Establish Connection

Please refer also to chapter Locating serial PC port.



Establish connection:

1. Connect serial cable to Eval-Kit connector X7a
2. Connect serial cable to USB port of you PC
3. Start RSP_Scope software
4. Select Port at baudrate 460800
5. Press OK

Following screen shopuld appear:

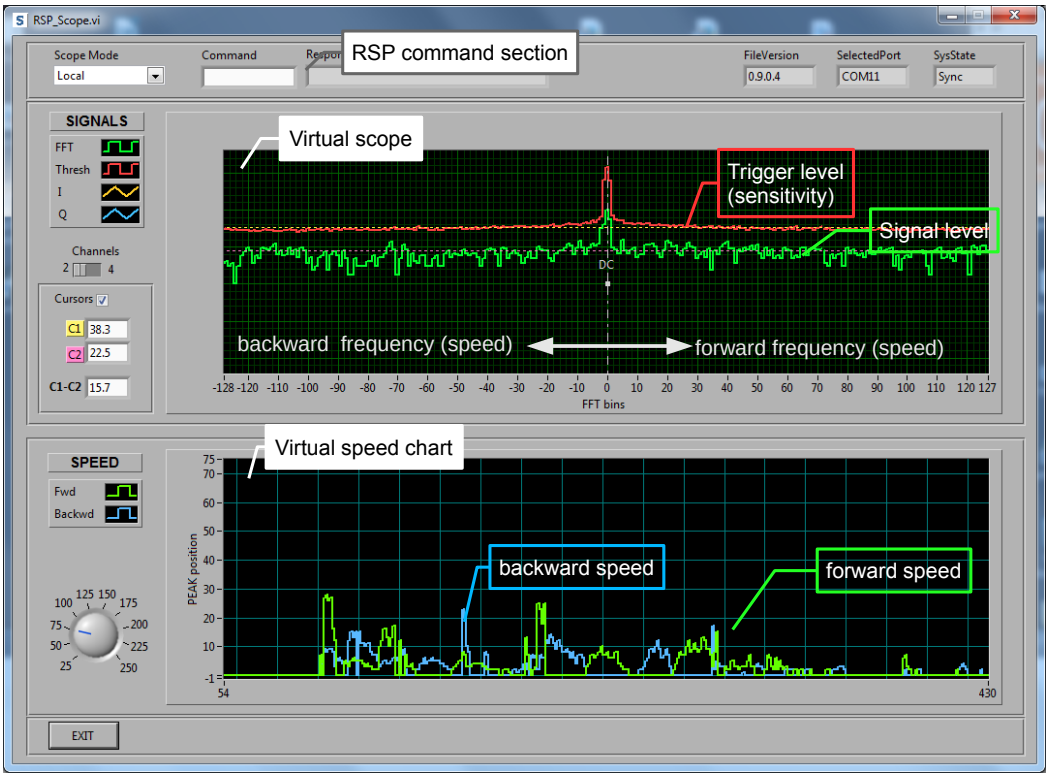


Fig. 3: Initial RSP Scope screen showing noise (top) and movement history (bottom)

Virtual scope (upper screen) has logarithmic Y-axis showing signal level. Therefore, noise looks very high. Refer to the RSP datasheet for more explanations.

Interpreting Virtual Scope Display

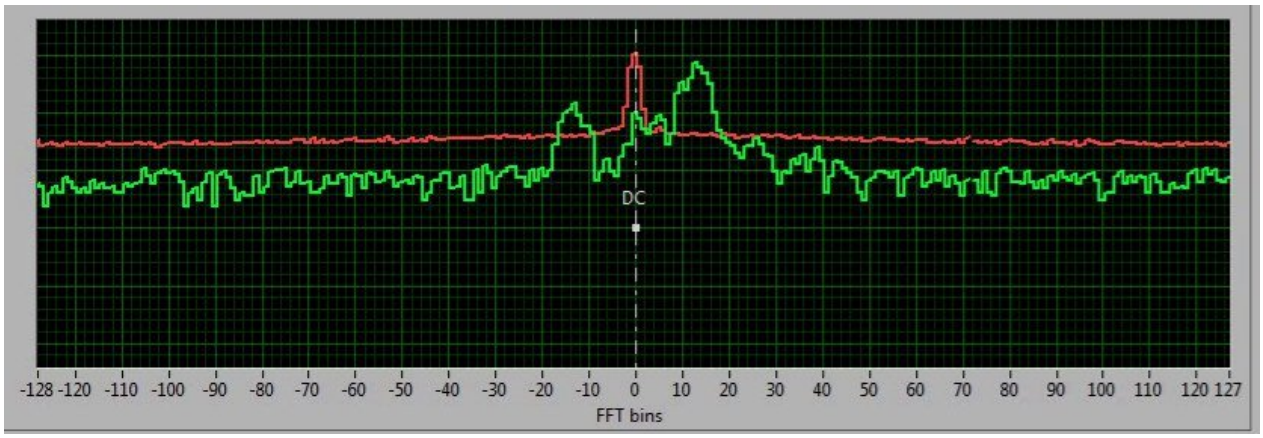


Fig. 4: Person walking towards a two channel I/Q "stereo" sensor

Highest peak on right side shows speed of a person walking towards the sensor.
(Peak on the left side is due to the sensor I/Q inbalance and phase error)

Speed scale (X-axis) is related to the 256 point FFT signal processing algorithm and represents the doppler frequency. Positive frequency represents approaching, negative frequency receeding object.
Please find more details on speed interpretation in chapter Background Information.

Y-axis represents the signal level (FFT magnitude) in a logarithmic form. The higher the reflectivity of the object, the higher the level.
→ Level depends on:

- Size of moving object
- Material of moving object
- Distance of moving object

RSP1 sets detection output, if peak exceeds the red threshold (sensitivity) and if direction corresponds th the setting of parameter ***A05*** or DIP-switches 3 and 4.

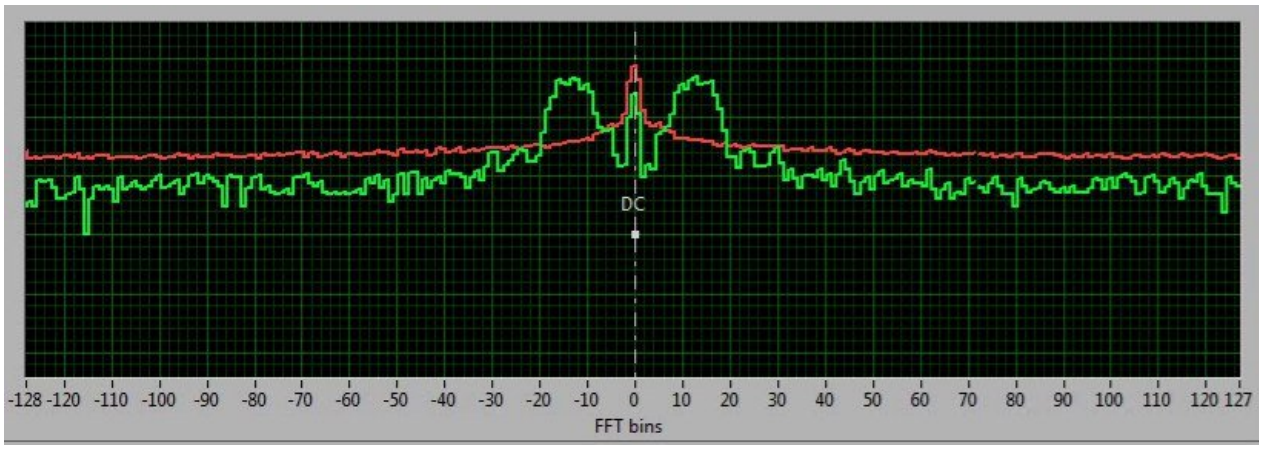


Fig. 5: Person walking towards a single channel "mono" sensor

Single channel sensors like K-LC1 or K-LC3 produce two similar peaks and therefore do not allow to detect movement directions.

Horiztontal cursors may be activated on order to measure signal to noise ratio in dB.

Adding IQ Signal Display

I/Q signal display appears at Channel switch position 4.
IQ display display directly the sensor's output signals that are captured by the RSP AD converter.
Please refer to chapter Doppler Signal Basics for more details on IQ signals.

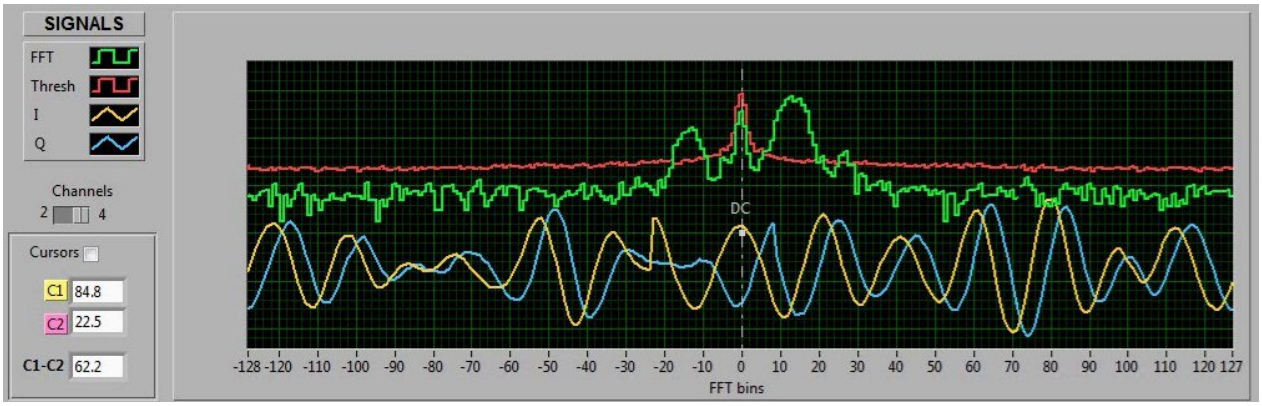


Fig. 6: Frequency and Time signal of moving person towards sensor

Using the Command Feature

You may read and set parameters in the command section while RSP_Scope is running. Example: check influence of parameter ***$A02*** on the red theshold level. Use same syntax as for RSP_Terminal.

Interpreting Speed Chart Display

Chart displays object speed as a function of time. If IQ sensors are used, direction can be discriminated.
X-axis: Time (256* sampling time)
Y-axis: Speed (FFT bin)

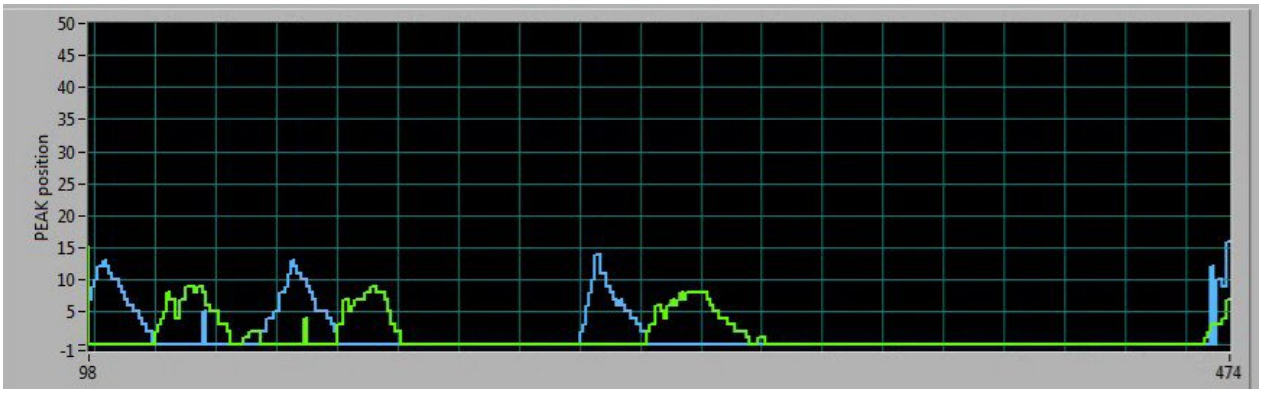


Fig. 7: Speed of person moving forwards and backwards

In future versions of RSP_Scope, Axis will be scaled in physical time and speed units.

RSP1_Eval-Kit Hardware

Complete schematics are provided with the Evaluation Kit.
Additional information can be found in the RSP1 chip data sheet.

Power Supply

Stable and low noise power supply is essential for optimal sensor results.
For details, please refer to the Evaluation Kit circuit schematics and to the RSP1 data sheet.

RSP1_Eval-Kit may be powered bay different sources. Most convenient way is using the USB 5V power from Personal Computer. USB power is very noisy. The evaluation kit uses a switched step-up regulator, followed by a linear power supply resulting in a very clean power supply.

Eval-Kit provides 3 independent and decoupled power inputs:
- 5V USB power at X7a
- 5V USB power at X7b
- 6 .. 12VDC external supply at X4 and X5

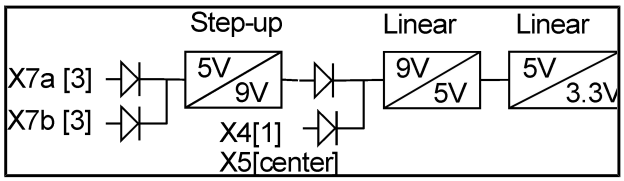


Fig. 8: Evaluation Kit low noise supply concept

Digital Output

RSP1_Eval-Kit provides an optically isolated digital output with a maximum 28VDC, nominal 20mA driving capability. The output is completely floating for maximum flexibility.

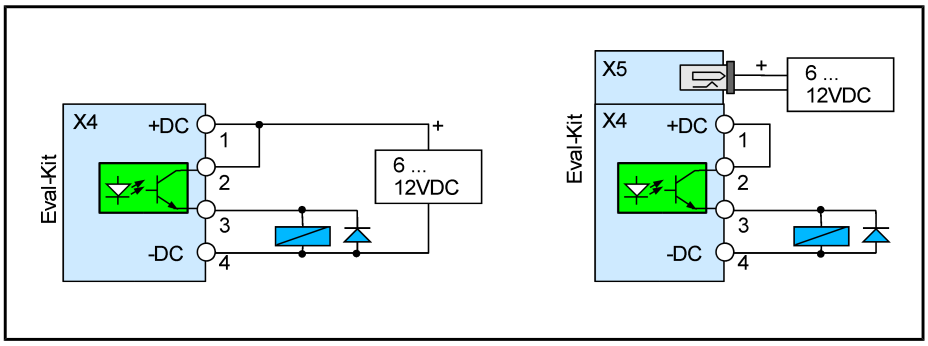
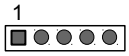


Fig. 9: Output wiring examples using external supply for output and system power

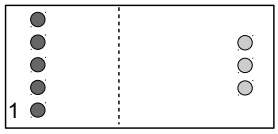
Connector Pins

X1 K-LCx connector

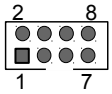
Pin	Signal	Description	Connector top view
1	IF Q	Doppler Signal (“Quadrature”)	
2	Vcc	Sensor Power 5V or 3.3V, depending on Jumper J1 position	
3	IF I	Doppler Signal (“In Phase”)	
4	GND	Sensor Ground	
5	VCO	FM output, not used	

X2 K-LCx connector

Located on backside of the Eval-Kit

Pin	Signal	Description	Sensor mount on PCB backside
1	IF Q	Doppler Signal (“Quadrature”)	
2	Vcc	Sensor Power 5V or 3.3V, depending on Jumper J1 position	
3	IF I	Doppler Signal (“In Phase”)	
4	GND	Sensor Ground	
5	VCO	FM output, not used	

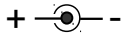
X3 K-MCx connector (alternate sensor)

Pin	Signal	Description	Connector top view
1	GND	Sensor /enable	
2	Vcc	Sensor Power 5V or 3.3V, depending on Jumper J1 position	
3	GND	Sensor Ground	
4	IF Q	Doppler Signal (“Quadrature”)	
5	IF I	Doppler Signal (“In Phase”)	
6	VCO	Not connected	
7	IF Q DC	Not connected	
8	IF I DC	Not connected	

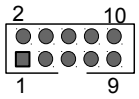
X4 Digital output and power connector

Pin	Signal	Description	Connector top view
1	+DC	+6 .. 12V power supply input (in parallel to X5 center pin)	
2	+DOUT	Opto isolated detection out plus side	
3	-DOUT	Opto isolated detection out minus side	
4	GND	Ground power supply input (in parallel to X5 outer contact)	

X5 power supply input

Pin	Signal	Description	Connector top view
1	+DC	+6 .. 12V power supply input (in parallel to X4 pin 1)	
2	GND	Ground power supply input (in parallel to X4 pin 4)	

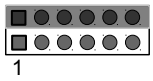
X6 Digital I/O and SPI

Pin	Signal	Description	Connector top view
1	NC		
2	GND	Signal Ground	
3	NC		
4	Detect out	digital processor output: high at detection + hold time	
5	*MISO*	*SPI Master-In-Slave-Out*	
6	*CMD Tx Enable*	*Enable signal for RS-485 drivers*	
7	*SCK*	*SPI Serial clock*	
8	*MOSI*	*SPI Master-Out-Slave-In*	
9	*nSS*	*SPI slave select*	
10	GND	Signal Ground	

Grey signals: reserved for future implementation

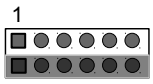
X7a Serial Command Interface

Outer row of X7: 38400Baud 3.3V command interface.
FTDI compatible pin layout.

Pin	Signal	Description	Connector top view
1	GND	Power GND FTDI cable black wire	
2	NC	Not connected	
3	+5V	Power supply input	
4	RXD	serial UARTdata input	
5	TXD	serial UART data output	
6	NC	Not connected	

X7b Serial Debug Interface

1Inner row of X7: 38400Baud 3.3V command interface
FTDI compatible pin layout.

Pin	Signal	Description	Connector top view
1	GND	Power GND FTDI cable black wire	
2	NC	Not connected	
3	+5V	Power supply input	
4	RXD	serial UARTdata input	
5	TXD	serial UART data output	
6	NC	Not connected	

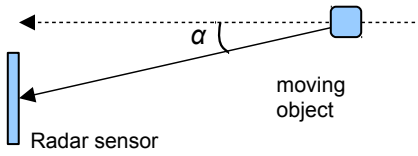
Serial Debug Interface is also used for updating RSP1 firmware

Background Information

Doppler Signal Basics

A moving object in range of a Radar sensor (often called “transceiver “) generates a low frequency output signal. Frequency depends on the object speed. Amplitude depends on distance, reflectivity and size of the object. Doppler frequency f_d is proportional to the object speed v:

$$f_d = v \cdot \frac{44\,Hz}{km/h} \cdot \cos\alpha \qquad v = \frac{f_d}{44\,Hz \cdot \cos\alpha} km/h$$



Note that the angle of the moving object reduces Doppler frequency.

I/Q Doppler Signals

I/Q sensors like K-LC2, K-LC5, K-LC6 and others produce 2 output signals, that are phase shifted by 90°. Main advantages:

- Forward / Backward movement differentiation
- Efficient interference suppression
- Vibration suppression

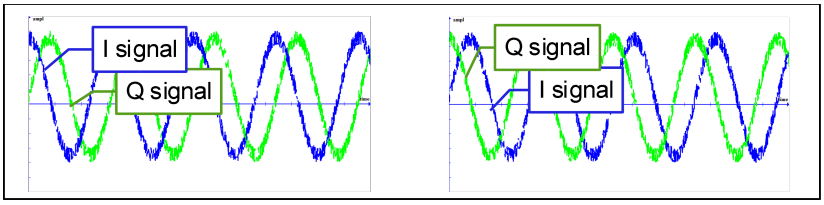


Fig. 10: I/Q signals left: approaching; right receding movement

FFT Fast Fourier Transform

Explanations go beyond the scope of this document. Please refer to literature (e.g. http://en.wikipedia.org/wiki/Fast_Fourier_transform and to the RSP1 datasheet.
Fortunately, RSP1, the user does not have to care about the details on FFT.

FFT represents in fact many narrowband filters that reduce noise amplitude. RSP1 uses 256 point FFT resulting in 128 bins (filters) for each forward and backward movements.
This kind of detection results in a much better sensitivity than simple comparator solutions. Theoretical gain in S/N ratio by using a 256pt (2 8) FFT is 10 * log(8) = 24dB. In reality, more than double detection distances can be reached compared to comparator solution.

RSP1 debug port and RSP_Scope help understanding using FFT in movement and speed sensors.

Sampling Rate and Bandwidth

Chosing optimal sampling rate is crucial for best detection results.
There are close relationships and dependencies between

- size of FFT (RSP1 uses 256pt Fast Fourier Transform)
- sampling rate
- detectable speed range
- speed resolution
- amplifier bandwidth
- system sensitivity (signal to noise ratio SNR)

Minimum Sampling Rate

Sampling rate *fs* must be at least twice the highest Doppler frequency appearing in the application.

$f_s > 2 \cdot f_d$ (Nyquist criteria)

However, the higher the sampling rate, the lower the frequency resolution:

$d_f > FFTn / f_s$ (In RSP1: FFTn = 256)

Maximum Amplifier Bandwidth

Amplifier bandwidth must be significantly lower than the maximum frequency mentioned in Fig. 11.
2nd order lowpass filter is recommended. Otherwise, aliasing effects will occur. (Wikipedia http://en.wikipedia.org/wiki/Nyquist%E2%80%93Shannon_sampling_theorem).

Sampling Rate Table

Sampling rate can be set by parameter ***S03.***

Parameter ***S03***	sample rate Hz	resolution Hz	max. frequency Hz	resolution km/h	max speed km/h	response time ms [1)]
01	1'280	5	640	0.11	14.5	200
02	2'560	10	1'280	0.23	29.1	100
03	3'840	15	1920	0.34	43.6	67
04	5'120	20	2"560	0.45	58.2	50
05	6'400	25	3'200	0.57	72.7	40
06	7'680	30	3'840	0.68	87.3	33
07	8'960	35	4'480	0.80	101.8	29
08	10'240	40	5'120	0.91	116.4	25
09	11'264	44	5'632	1.00	128.0	23
0A	22'530	88	11'265	2.00	256.0	12

Note 1): response time on host interface. Digital output depends also on params $A03 and $S02

Fig. 11: Detectable speed depend on parameter S03

Rule of Thumb for your application:
Use lowest possible amplifier bandwidth at highest possible sampling rate

Using Serial Interfaces in parallel

RSP_Scope connected to Debug Interface X7b) and RSP_Terminal (connected to Command Interface X7a) may be used in parallel. A 2nd FTDI cable is required for this.
This RSP1 feature becomes important for debugging applications with a host CPU connected to the RSP1 Command Interface with the RSP_Scope connected to the debug port.

General Radar Installation Tips

Radar for movement detection is a very reliable and robust technology. It is insensitive to heat, wind, dust, sunlight and other influences.

However, there are some important issues to take into consideration:

- Sensitivity to fluorescent light (→ use IQ modules and/or RSP1 FFT Filter features)
- Material and thickness of cover
- Sensitivity to vibrations (→ use I/Q modules)

The following application notes should help to optimize your application.

Cover

Every cover has some influence on the shape of detection field and the achievable maximum distance. Radar can „view“ through plastic and glass of any color. This makes a high degree of design freedom. Nevertheless, some rules should be considered.

- Cover must not be metallic.
- Plastic coating with colors NOT containing metallic or carbon particles.
- Distance between cover and front of Radar sensor > 1cm
- Best cover material is Polycarbonat or ABS
- Best cover thickness is 3-4mm
- Vibrations of sensor module relatively to the cover should be avoided, because this generates signals that can trigger the output

Interference Factors

RSP1 designs are much more robust against interference factors than traditional Radar based designs. Nevertheless, take care on the following tips.

Fluorescence Light

- Do not mount Radar modules directly facing to fluorescent lamps
- Use sensors at the lowest possible sensitivity for your certain application

Radar is susceptible to fluorescent lamps, even if controlled by electronic ballasts. These lamps produce a 100Hz (50Hz mains, Europe) or 120Hz (60Hz mains, USA) Radar signal that is similar to the signals produced by a person walking at about 2km/h.
RSP1 features adaptive filters, intelligent suppression algorithms and selective programmable FFT filters. Refer to RSP1 datasheet.

Rain

- Prevent cover to get wet
- The lager the distance to rainy environment, the smaller the rain effect.

Raindrops can be interpreted by Radar as moving objects and may trigger the output.

Vibrations, Ventilators etc.

- Radar based sensor and its cover should be mounted stable to prevent vibrations
- Try to prevent objects like ventilators in the sight of the detection field

Sensitivity and Maximum Range

Sensitivity defines the necessary signal strength at the Radar sensor to trigger the output.
RSP1 allows adjusting sensitivity by potentiometer and/or by parameters.

Trigger distance at same sensitivity setting can vary depending on

- Type of moving object (person, car etc.).
- Moving direction of the object

Further Reading

- RSP1 datasheet contains important information on signal processing and hardware design.
- Schematics of the RSP1 Evaluation Kit are included on the installation media.
- Application note AN-04 contains amplifier examples.
  http://www.rfbeam.ch/fileadmin/downloads/appnotes/AN-04%20TypicalSignalAmp.pdf
- Application Note AN-03 contains tips for cover ("Radome") and housings
  http://www.rfbeam.ch/fileadmin/downloads/appnotes/AN-03-Radome.pdf

Revision History

Version 0.2	Sept 21, 2014	Preliminary release
Version 0.3	Nov 01, 2014	Preliminary release

RFbeam does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and RFbeam reserves the right at any time without notice to change said circuitry and specifications.

Features

- Universal Doppler Radar signal processor
- Complete I/Q Radar sensor interface
- Complex FFT based signal processing
- Double detection distance compared to traditional solutions
- Object speed and direction detection up to 250km/h
- Efficient adaptive interference suppression
- Stand-alone or hosted operation
- Evaluation Kit available

1 Applications

- Movement detectors
- Lighting control systems
- Security applications
- Object speed detection

2 Description

2.1 Application Example

RSP1 contains all Doppler signal processing.
Up to now, development of Doppler Radar signal processing has been a time consuming matter and needed experience in analog and digital electronics.
With RSP1, typical applications need minimal external components. Configuration can be made by switches and potentiometers or fully digital via serial interface.

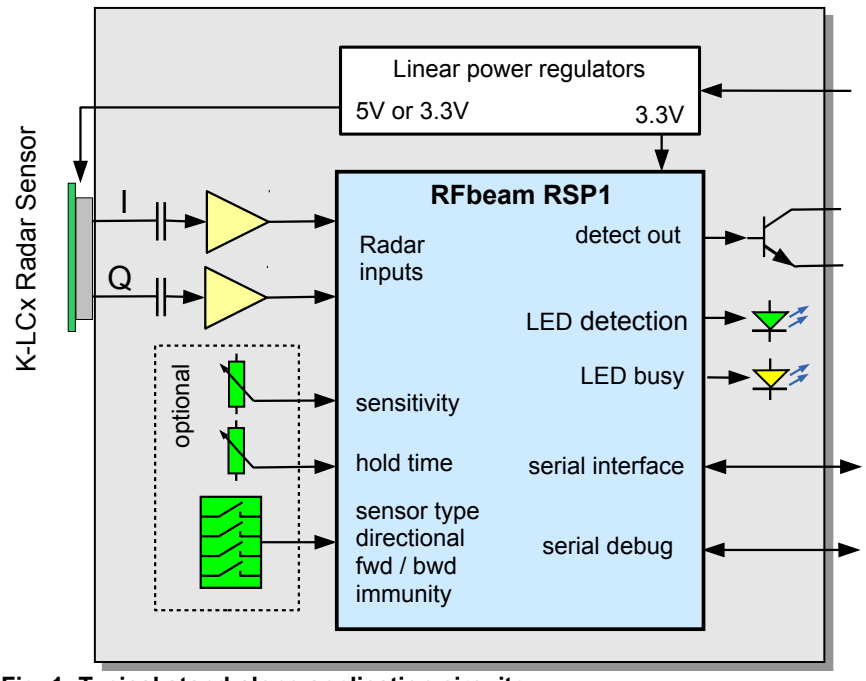


Fig. 1: Typical stand-alone application circuitry

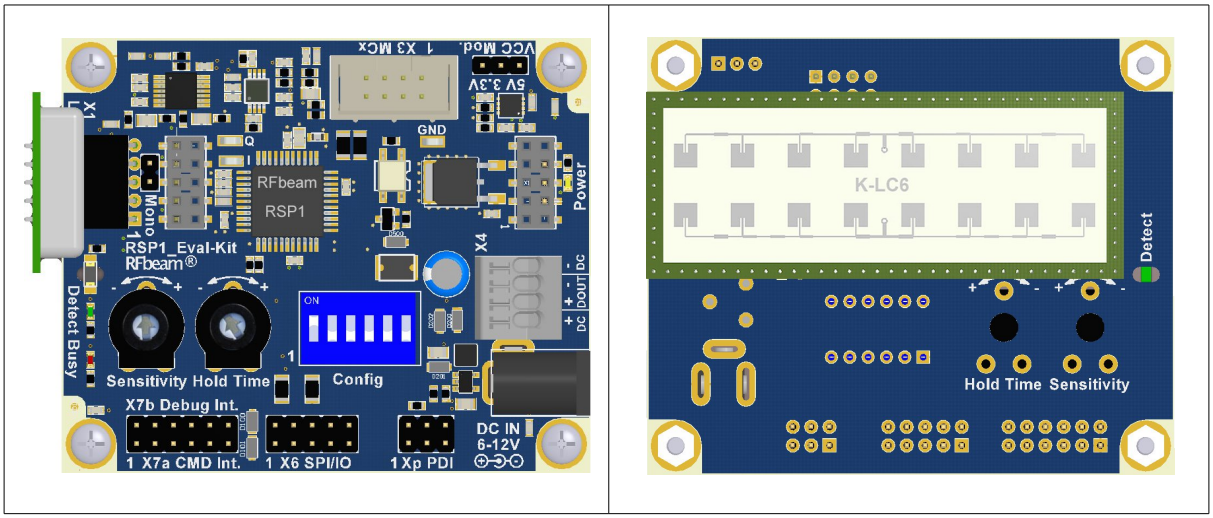
2.2 RSPx Family

RSP1 is the first member of RFbeam Radar signal processors.
The RSPx family helps users concentrating on their application know-how instead of investing time and money in raw signal processing.
RSP1 contains all signal processing for Doppler Radar. It covers slow movement detectors as well as speed estimators up 250km/h.
It can be used as stand alone processor or as a co-processor in higher complexity systems.
User has only to add an input amplifier and digital output drivers and gets a high performance detection system.
Evaluation and development is supported by the **RSP1 Evaluation Kit** reference design.

2.3 Key Data

- 12 Bit ADC
- Differential analog inputs for I and Q signals
- Internal programmable gain amplifier
- Sampling rates from 1280Hz to 22.5kHz
- Efficient 256pt complex FFT
- Logarithmic detection algorithms
- Adaptive noise and interference analysis and canceling algorithms
- Serial command and debug/streaming interfaces
- Commands include peak magnitude, frequency and sign, noise level and many more
- Highly configurable by serial interface and/or digital and analog inputs
- Application settings can be down- and uploaded from chip

2.4 RSP1 Evaluation Kit



RSP1_Eval-Kit; Left: K-LC2 sensor on front connector; Right: Backside equipped with K-LC6 sensor

With RSP1 Evaluation Kit, you may explore most features of RSP1 working with different RFbeam sensors. 5 different sensors are included in the kit.
Using a RSP_Terminal you have access to more than 30 parameters. Explore FFT, noise and other signals with the RFbeam SerialScope PC Software, that.also makes part of the kit.
All schematics, PCB layout and BOM are included as a reference.

3 Sensor Configurations

RSP1 Chip may be used with one or two sensors. Sensors can not be used in parallel, but as alternative sensor connected to the Alt_RADAR inputs. Inputs can be selected by parameter ***S01***.

Channels	Sensor examples	Comments
1 ("mono")	K-LC1a, K-LC3	Lowest cost. Mostly used for indoor applications
2 ("stereo")	K-LC2, K-LC5, K-LC6, K-MC1	Directional detection, excellent interference suppression

Table 1: Sensor Configurations

3.1 Single channel vs Dual channel (I/Q) processing

RSP1 can be operated with dual channel ("stereo") I/Q sensors as well as with one channel ("mono") sensors (see Table 1: Sensor Configurations).

Feature	Dual channel	Single channel
Directional detection (receeding / approaching)	x	
Interferenc suppressin (fluorescence lights, vibrations and others)	x	
Noise suppression (better sensitivity)	x	
Lower cost		x

Table 2: Dual channel versus single channel comparison

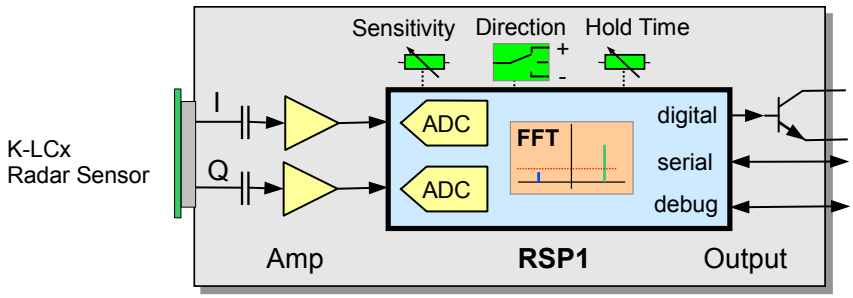


Fig. 2: Typical dual channel architecture

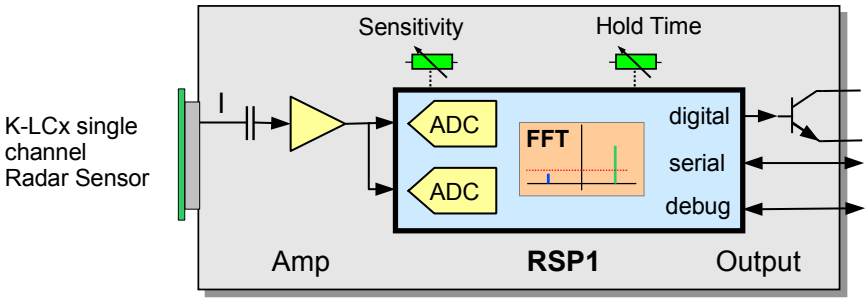


Fig. 3: Typical single channel architecture

4 RSP1 Architecture

4.1 Data Acquisition

An internal, programmable differential amplifier allows gains from 1 to 16.
RSP1 works with 2 12Bit ADCs, sampling rate is selectable between 1'200Hz up to 22.5kHz in 10 steps.
This corresponds to maximum speeds from 13km/h to 250km/h.

4.2 Data Processing

Processing is based on a complex FFT and on an adaptive noise threshold. Many parameters allow adjusting and optimizing the performance for many different applications.

Advantages of FFT

FFT stands for Fast Fourier Transform, that allows signal processing in the frequency domain (see details on http://en.wikipedia.org/wiki/Fft).
Processing of the Quadrature Doppler signals is performed by a complex FFT. Using FFT results in much better performance than using simple comparator designs or time domain processing.

The RSP1 FFT implementation leads to sophisticated movement and speed detectors:

- Better S/N (21dB with 256pt FFT) → 2 to 3 times larger detection range
- Inherent object speed detection
- Reliable distiction between approaching / receding objects
- Efficient interference suppression through complex FFT (fluorescent light, rain, vibrations …)
- Narrowband filtering of known interference frequencies
- Selective and adaptive noise threshold capability

RSP1 Hardware Architecture

The processor architecture allows data acquisition and processing in parallel. Only a few external components are needed thanks to the high integration level including EEPROM and precision clock generator.

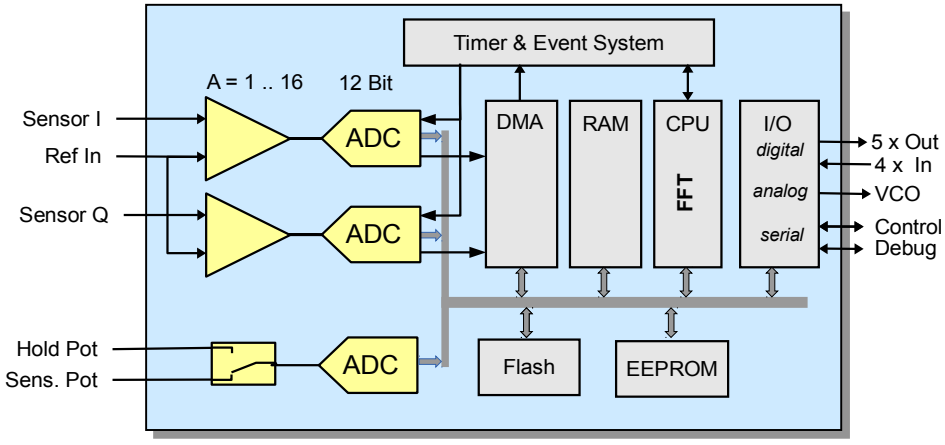


Fig. 4: RSP1 simplified block diagram

5 Performance data

5.1 Overview

RSP1 is working at an internal clock frequency of 32MHz.
Radar I and Q signals pass a programmable gain amplifier (A=1 to 16). A 12Bit differential ADC running at a 500kHz clock converts the amplified signals. I and Q channels are acquired quasi parallel with a time shift of 2us.
Complex 256pt fixpoint FFT runs in parallel to the data aqcuisition. Time signal passes a Hanning window and is then processed by the FFT.
Acquisition is interrupted only by a 300us windowing calculation time. All other signal processing is performed in parallel to the data acquisition.

5.2 Internal Timing

Sampling timing depends on setting of parameter S03 (sampling rate). This results in following FFT resolutions and measuring speed ranges:

Parameter ***S03*** (hex)	fs (sampling freq.)	df (resolution)	max. speed	remark
01 … 08	S03 value * 1280Hz	5Hz to 40Hz	4.5km/h to 116km/h	allows direct readout of frequency
09	11.254kHz	44Hz (1km/h)	127km/h	allows direct readout of speed in km/h
0A	22.528kHz	88Hz (2km/h)	255km/h	allows direct readout of half speed

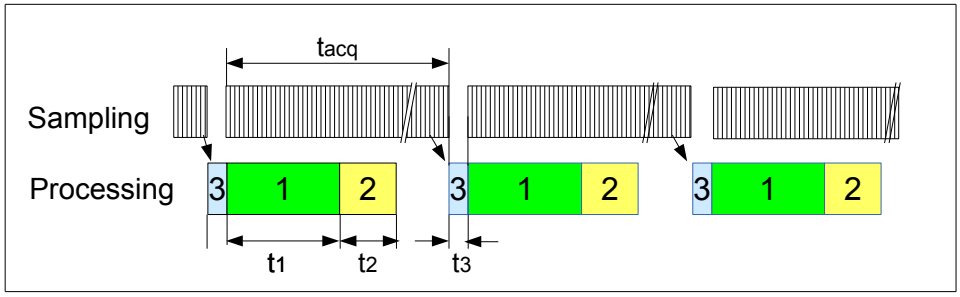


Fig. 5: Acquiring and processing executes in parallel. A small gap (t3) occurs during windowing

t_{acq} *= 256 * 1/fs = 11.4ms … 200ms (with fs = 22.5kHz … 1280kHz)*
t_1 *= 7.7ms FFT*
t_2 *= 2ms Logarithmic result conversion*
t_3 *= 0.3ms Hanning window calculation*

ADC Sampling of both channels is performed quasi-parallel with a maximum time shift of 2us max.

5.3 Response time

Response time on parameter requests on sampling rate *fs* (parameter S03):
t_{Rmin} *= 11.4ms * A03 value (S03 = 0A)*
t_{Rmax} *= 200ms * A03 value (S03 = 01)*

Update time on result parameters and digital outputs depend on sampling rate *fs* (parameter S03), on and immunity value (parameter A03) and on FFT avaraging (parameter S02).
t_{UPDmin} *= 11.4ms * A03 value (S03 = 0A, S02 = 00) or 22.8ms * A03 value (S02 = 01)*
t_{UPDmax} *= 200ms * A03 value (S03 = 01, S02 = 00) or 400ms * A03 value (S02 = 01)*

See also chapter 8.4 Sampling Rate and Frequency Resolution

5.4 Internal signal representation

RSP1 computes the complex amplitude spectrum of the input I/Q signals.

Analog conversion is performed with 12Bit resolution. In order to get better accuracy in fixpoint calculations, ADC result is left shifted by 4 bits resulting in a value range from -32'768 … 32'767.

All internal processing and signal parameter settings are based on logarithmic FFT results. This allows optimal handling of small signals and fits well to the Radar signal vs. object distance behaviour.

Step	Processing stage	Value range	Remark
1	Input signal (Radar Common input = 1.65V)	3.3Vpp (A=1) .. 206mVpp (A=16)	resolution 806µV/bit @A=1
2	Internal amplification	A = 1, 2, 4, 8, 16	Parameter S09
3	AD conversion 12 bit signed	-2048 … + 2047	2 channels in parallel
4	Internal representation * 16	-32768 … + 32767	used to enhance FFT accuracy
5	16/32 bit fix point FFT with Hamming window	magnitude 0 … 23'168	
6	log conversion in fixpoint form x.yy	log10 as integer: **0 … 437**	corresponds to 0 … 4.37

Table 3: Internal processing stages

Value	Range / conversion	Remark
Input voltage at Radar input	1.65Vp = 1.17Vrms	Gain A = 1; parameter **S09= 0**
Input voltage at Radar input	193mVp = 72.9mVrms	Gain A = 16; parameter **S09 = 4**
Maximal internal signal level	437	logarithmic magnitude level * 100
Internal signal level relation to dB	dB ≙ value / 5	
Internal FFT magnitude at 1Vrms input	[dBVrms] = value - 86	430 / 5 = 86
Max. input frequency	640Hz .. 11.25kHz	sampling rate / 2 (see parameter S03)
Frequency resolution	sampling rate / 256	5Hz ... 88Hz
Speed resolution	0.1km/h ... 2km/h	corresponds to 5Hz to 88Hz

Table 4: Useful signal level conversions

6 Detection Algorithm

Detection algorithms are based on the complex FFT (Fast Fourier Transform) of the I and Q analog signal inputs.FFT output logarithmic in order to get good signal processing conditions for both large and small signals.
FFT represents in fact many narrowband filters that reduce noise amplitude. RSP1 uses 256 point FFT resulting in 128 bins (filters) for each forward and backward movements.
This kind of detection results in a much better sensitivity than simple comparator solutions.
Approximative gain in S/N ratio by using a 256pt FFT is 10 * log(128) = 21dB. In reality, more than double detection range can be reached compared to comparator solution.

Signals and processing behaviour may be explored by the RFbeam tool RSP1_Scope, connected at the serial debug port (see 7.5 Serial Debug Interface)

6.1 Adaptive noise detection

The advanced noise detection technique leads to the outstanding sensitivity of the RSP1 solution. Noise is measured separately for each frequency represented by the FFT results. Two stages in noise measurement exist:

1. After power-on, an initial noise curve is built by measuring the mean of each FFT frequency bin. Number of means (measuring time) can be selected by Parameter ***S04.***

2. Adaptive mean is continuously built during operation. Adaptation time constant ca nbe selected by Parameter ***S0C***

If using I/Q stereo sensors (like K-LC2, K-LC5 etc.), noise cancellation is very efficient, because movement Doppler signals can be efficiently distinguished from noise signals.

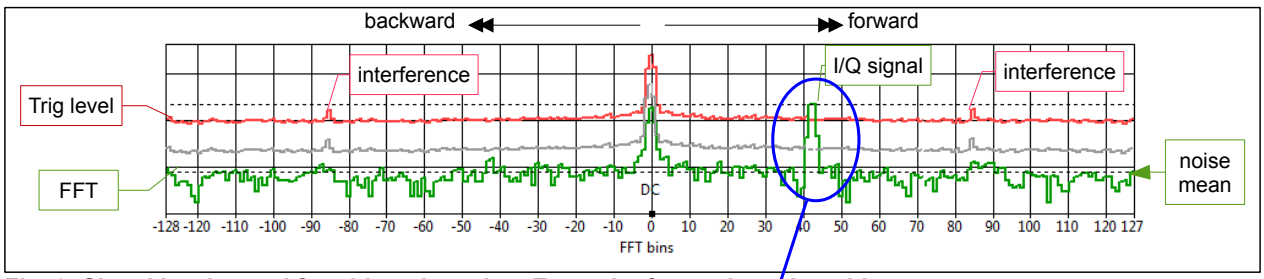
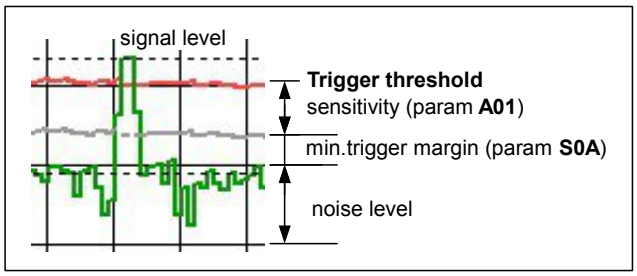


Fig. 6: Signal levels used for object detection. Example: forward moving object

Trigger level results from the sum of adaptive noise threshold (Grey plot) and the sensitivity selected by parameter ***A02***.

Signal in the center is the DC offset caused by the amplifier and ADC converter.



Noise and small signals looks very strong in logarithmic form of the FFT magnitude. Remember that a signal difference of 1mVrms to 2mVrms produces same logarithmic magnitude difference as a difference from 500mVrms to 1Vrms.

6.2 I/Q Signal Processing

RSP1 supports I/Q processing by using complex FFT. I/Q Doppler signals are phase shifted by + 90° or -90°. Those signals appear either in the real(right) plane or in the imaginary (left) plane of the FFT output. Signal in the center is the DC offset caused by the amplifier and ADC converter and can be ignored. (see Fig. 8).

Main advantages of using I/Q sensors compared to single channel sensors:

- Forward / Backward movement differentiation
- Efficient interference suppression
- Vibration suppression

Even if directional detection is not required, I/Q processing allows significantly better immunity suppression.

Doppler I and Q signals in Time domain at RSP1 Radar inputs:

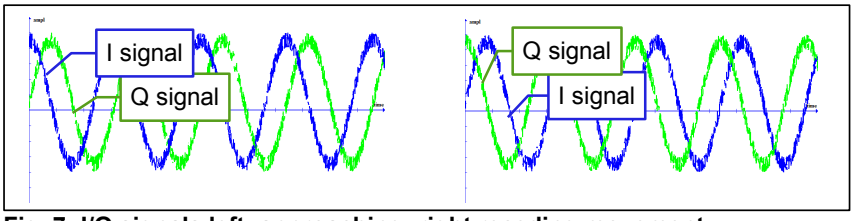


Fig. 7: I/Q signals left: approaching; right receding movement

Doppler signals in Frequency domain, processed by RSP1:

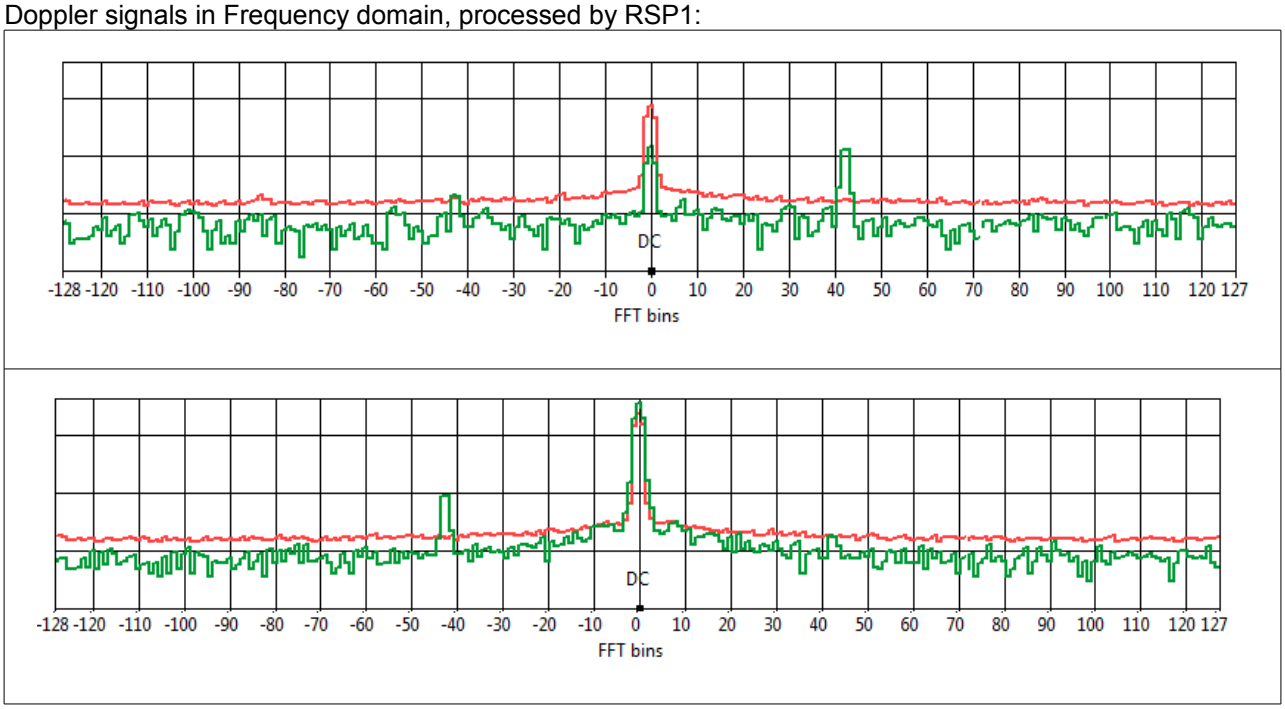


Fig. 8: FFT magnitude of forward moving and backward moving objects

Single channel sensors produce same signal on left and right plane of the complex FFT.

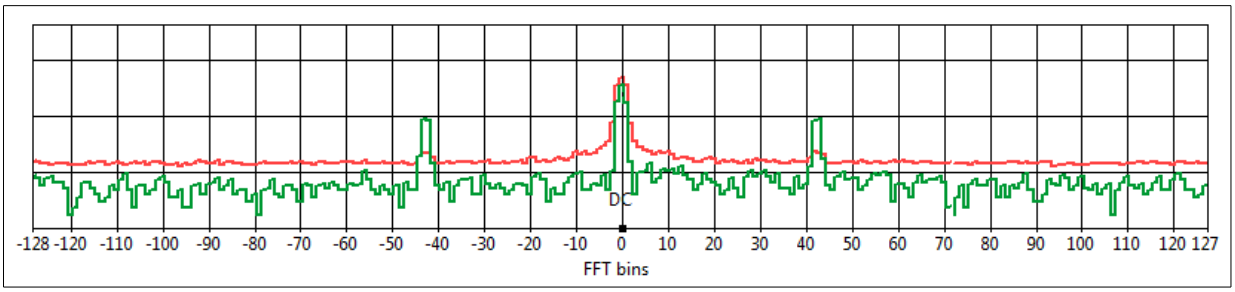


Fig. 9: Single channel signal appears symmetrically in the left and right half

6.3 Interference Filter

Typical interferences appear symmetrically on the left and right plane in the FFT output. Typical noise source are electronic ballasts and fluorescent lights.
Therefore those interference signals may easily be distinguished from I/Q Doppler signals produced by stereo sensor modules:
RSP1 adapts threshold (red line) for noise, but not for real I/Q Doppler signals. See also chapter 6.1 Adaptive noise detection

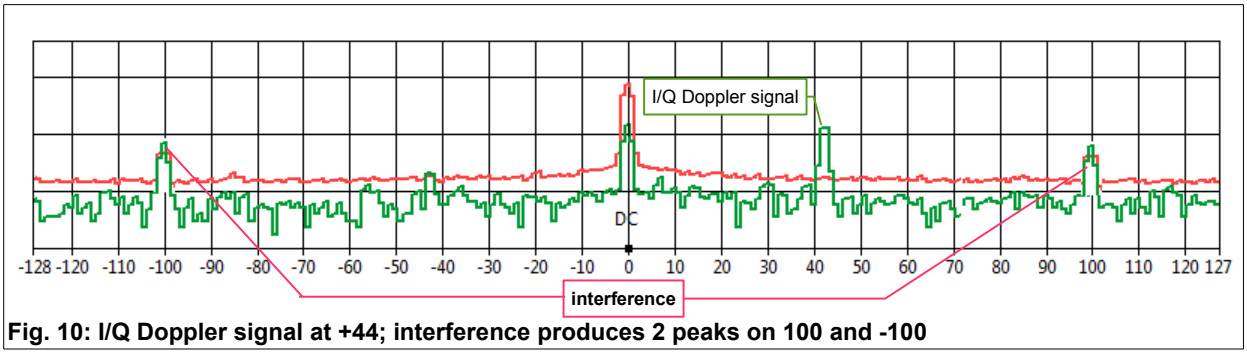


Fig. 10: I/Q Doppler signal at +44; interference produces 2 peaks on 100 and -100

Interferences like in Fig. 10 look different from I/Q Doppler signals caused by movement.
With single channel modules, Doppler signals (Fig. 9) look similar to interferences.

6.4 Random Noise Filter

RSP1 offers different mechanisms in order to suppress influence of stochastic noise:
Random noise produces stochastically distributed peaks in the FFT output and can be reduced by averaging. FFT averaging can be enabled by parameter ***S02.***
Noise peaks exceeding trigger threshold are counted and must exceed a counter threshold adjusted by parameter ***A03***.

6.5 Selective FFT Filter

Up to 8 single frequencies may be suppressed by means of array parameters X20 to X27.
Each value represents an FFT bin, that will be masked out from triggering.
Example:
Mask out frequencies 100Hz and 1kHz at sampling rate 2560Hz (Param ***S02*** = 02).
Set parameter X20=000A and param X21=03E8. For more details see chapter FFT Filter

7 Interfaces

RSP1 provides different interfaces for configuration and control signals. RSP1 can be used as a stand-alone processor or in conjunction with a host controller.

- Command interface: Standard UART interface for parameter settings with 38'400Baud.
- Debug Interface: High speed UART interface for debug purposes with 460'800Baud (Parameter ***S06***).
  This interface acts also as bootloader interface for software updates.
- Digital I/O: Control signals for status LED, digital outputs and optional SPI interface.

7.1 Analog I/O

Please refer to chapter 13 Sample Schematics for details of analog signal handling.
Range of RADAR input signals depend on the internal gain setting by parameter ***S09:***
S09 = 0: range 3.3Vpp; ***S09 = 4:*** 200mVpp.

Pin	Function	Remark
AVcc	Power supply for chip analog section	Decouple well: see Fig. 14
RADAR_AREF	ADC reference voltage	Vcc/2 (1.65V), connect to RADAR_COMMON
RADAR_COMMON	Input reference voltage	Vcc/2 /1.65V) decoupling see Fig. 14
RADAR_I1	Radar in-phase signal (I)	Signal referenced to RADAR_COMMON
RADAR_Q1	Radar in-phase signal (Q)	Signal referenced to RADAR_COMMON
ALT_RADAR_I1	Alternative Radar I input	selected by parameter ***S01***
ALT_RADAR_Q1	Alternative Radar I input	selected by parameter ***S01***
ALT_RADAR_COMMON	Input reference voltage	connect to RADAR_COMMON
HOLD_POT	Optional hold time setting	Range 0 to Vcc/2. Function must be enabled by param. ***S07***
SENS_POT	Optional sensitivity setting	Range 0 to Vcc/2. Function must be enabled by param. ***S06***

7.2 Digital I/O

All digital inputs have internal pull-down resistors and are high active.
Secondary pin functions (IDx) are reserved for future versions.

7.2.1 Mode settings

- Input SETTING_MODE must be tied to Vcc in order to activate the setting inputs.
- Setting inputs are sampled at power ON only
- Settings can be over-written by sending similar software parameter commands

Pin	Function, if high (3.3V)	Remark
SENSOR_MONO	1 channel sensor connected	e.g. K-LC1a, K-LC3
DIR_MONO	no directional processing	detect both movement directions with I/Q sensors also
DIR_BACKWARD	detect receding movements only	DIR_MONO input must be low / left open
IMMUNITY	set extended interference immunity	
SETTING_MODE	enable setting inputs	if low or left open, setting inputs have no effect

7.2.2 Control Outputs

Digital outputs are high active push-pull circuits with typically 10mA driving power.

Pin	Function, if high (3.3V)	Remark
LED_BUSY	RSP is busy and is not detecting	Active during power-on learning
LED_DETECT	Active, as long as movement is detected	including hold time
DETECT_OUT	same signal as LED_DETECT	use for driving external hardware output
LOW_BANDWIDTH	set according to parameter ***S08***	optional use for external amp bandwidth limitation
CMD_TX_ENABLE	*reserved for future RS-485 expansion*	*active during serial transmission*
CMD_TX	Command interface UART Tx	see chapter 7.3 Host Command Interface
CMD_RX	Command interface UART Rx	see chapter 7.3 Host Command Interface
DETECT_SIGNAL	same signal as DETECT_OUT	optional use for digital signaling to host device

7.3 Host Command Interface

This is a 3.3V asynchronous UART interface:
Pins: Input: CMD_RX, output CMD_TX
Physical data: 38'400Baud, 8 databit, 1 stopbit, no parity, no handshake
Protocol: Client-Server protocol. RSP1 acts as server. See 8 Software Parameter Settings

This interface is supported by the RSP_Terminal tool.

7.4 SPI / IO Interface

This interface is reserved for future versions of RSP1.

7.5 Serial Debug Interface

Debug interface provides highspeed parameter access as well as streaming output of I and Q signals and FFT results signals over a serial UART interface.
This is a 3.3V asynchronous UART interface:

Pins: Input: DEBUG_RX, output DEBUG TX
Physical data: 460'800Baud (parameter ***S0B***), 8 databit, 1 stopbit, no parity, no handshake.
Protocols:
- Streaming protocol, supported by RSP_Scope tool. (see chapters below)
- Client-server protocol supported by RSP_Scope and RSP_Terminal tool
- Bootloader protocol. Proprietary, for use with RSP_PROG tool

7.5.1 Cyclic Signal Streaming

Cyclic signal streaming is a continuous data stream with no host intervention except start and stop.
This mode is initiated by commands ***D0001*** and ***D0002*** the **Host Command Interface** .
RSP1 then outputs cyclic binary data frames on **Debug Interface.**
Cyclic output stops at command ***D000*.**

Protocol Item	Binary data items on line DEBUG_TX	Format	Comment
Sync Header	0x24, 0x02, 0xa2, 0xe1, 0x5a, 0xd6, 0x19	7 Bytes	
Mode Byte	0x7a or 0x0F	1 Byte	***D00x1 or D00x2***
1024 or 2048 bytes for "Scope" display	**FFT** bin -128	High, Low Byte	
	Threshold bin -128	High, Low Byte	
	I signal sample 0	High, Low Byte	Only at commands ***D0002 or D0012***
	Q signal sample 0	High, Low Byte	
	….		
	FFT bin 127 High Byte, Low Byte		
	Threshold bin 127 High Byte, Low Byte		
	I signal sample 255	High Byte, Low Byte	Only at commands ***D0002 or D0012***
	Q signal sample 255	High Byte, Low Byte	
		High Byte, Low Byte	
		High Byte, Low Byte	
2 data bytes strongest object speeds	Forward frequency peak index 0 to 127	1 Byte	0: no peak, >0 speed
	Backward frequency peak index 0 to 127	1 Byte	0: no peak, >0 speed

Table 5: Debug cyclic and single shot protocol

7.5.2 Single Shot Signal Streaming

Single shot streaming is a client server protocol.
This mode is initiated by commands ***D0011*** and ***D0012*** at the Debug **or** Host Command Interface.
RSP1 then outputs one binary data frame on Debug Interface.
Data frame is the same as in the cyclic protocol described before in 7.5.1 Cyclic Signal Streaming

8 Software Parameter Settings

Parameters may be set by the command interface. It works at 38.4kBaud, 1 stop bit and no parity.

8.1 Parameter Storage

All parameters except real-time and debug parameters are permanently stored into the processor-internal EEPROM.

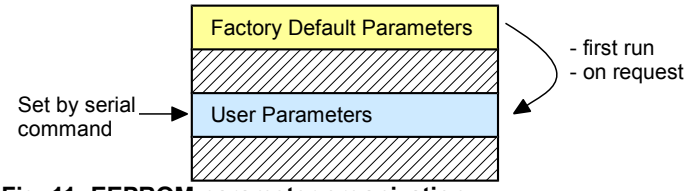


Fig. 11: EEPROM parameter organization

Parameters are divided into classes:

Parameter Type	Par. Class	EEPROM	Purpose
Application parameters	A	Yes	End-User specific settings in final application
System parameters	S	Yes	Application specific parameters
Array parameters	X	Yes	Application specific tables
Real time read parameters	R	No	Real-Time information on processing state
Real time write parameters	W	No	Real-Time commands
Debug parameters	D	No	Debug behavior control

Table 6: Setting parameter types and classes

8.2 Parameter Format

Parameter changes (except class W and D) will be directly stored into the EEPROM user space.
Parameters are set by a serial UART interface and may be set by a host CPU or by an ASCII terminal:

Physical format: 38.4KBaud, 8 bit data, 1 stop-bit, no parity ("8n1")
Format: Request with prefix $; answers come with @ prefix
<CR> represents Enter key (0x0D hex)

$	aa	P	nn	vv	<CR>	Example request	RSP response	Comment
Prefix	Optional Node ID	Parameter class	Number(Hex)	Value (Hex)	"Enter"	$A02<CR> $A0207<CR>	@A0209<CR><LF> @A0207<CR><LF>	Actual value request Set new value

Table 7: Setting parameter format (Node ID is reserved for future RSP1 derivatives)

8.2.1 Error messages (RSP response)

@E01: value out of limits
@E02: parameter number does not exist
@E03: parameter class does not exist
@E04: writing to EEPROM error
@E05: command format error
@E06: UART communication error

8.3 Parameter List

8.3.1 8 Bit Parameters

All values are in hexadecimal notation! Except values marked with *. *Column "R": needs reset*

Param.	default	min	max	Function	Description	R
Class A	(EEPROM)			**Application Parameters**	End-User specific settings in final application	
A00	*00*	*00*	*00*	*reserved*	*reserved for future use*	
A01	01	00	09	hold time	9: maximum hold time of detection output	
A02	09	00	09	sensitivity	9: maximum detection sensitivity	
A03	03	00	09	immunity	9: maximum immunity against interference	
A04	*00*	*00*	*00*	*reserved*	*reserved for future use*	
A05	00	00	02	direction	0: approaching; 1: receding; 2: both	
A06 … A0F	*00*	*00*	*00*	*reserved*	*reserved for future use*	
Class S	(EEPROM)			**System Parameters**	Application specific parameters	
S00	00	00	01	sensor type	0: stereo I/Q sensor; 1: mono sensor (1 channel)	x
S01	00	00	01	Use alternate analog port	1: ADC input on pin 2 and 3 instead of pin 44 and pin 1	x
S02	01	00	01	FFT average	1: averaging on	
S03	02	01	0A	sampling rate	rate = value*1280Hz, except 9: 11.264kHz; A: 22.53kHz	x
S04	10	01	40	start up learn	noise learn cycles after reset	x
S05	01	01	02	active sensors	*reserved*	x
S06	01	00	01	sensitivity pot	1: use potentiometer for sensitivity setting	x
S07	01	00	01	hold time pot	1: use potentiometer for hold time setting	x
S08	01	00	01	bandwidth	1: low bandwidth (digital output used for external filter)	
S09	04	00	04	ADC gain	gain = 2^n: 0 -->1; 1-->2; 2-->4; 3-->8; 4-->16	x
S0A	38	20	50	minimum trigger margin	minimum margin between noise and max. sensitivity	x
S0B	00	00	00	baudrate serial debug port	0:460800; 1:115200; 2: 38400	x
$S0C	00	00	FF	threshold adapt. speed	00:max. depending on sampling rate; >0: n*500ms / dB	
S0D … S0F	00	00	00	reserved	*reserved for future use*	
Class R	(immediate)			**Real-Time Read Params**	Read only parameters	
R00	-	00	01	detection active?	1: detection output active (includes hold time)	
R01	-	00	FF	detection speed	>0 peak position (FFT bin #)	
R02		0	FF	noise level mean	arithmetic mean over all FFT bins	
R03	-	00	02	operation state?	start up; learn; run	
R04	-	00	FF	software version	major.minor version (x.0 are preliminary versions)	
R10	*	--	--	software version string	Full software version and date string, max 40 characters	
R11	*	--	--	result string	SpeedFW, SpeedBW, MagFW, MagBW<CR>	
R20	*	--	--	get EEPROM hex string	Full 512 EEPROM bytes in Intel hex format	
Class W	(immediate)			**Real Time Write Params**	Volatile write parameters	
W00	-	00	01	force detection output	1: set digital detection output; 0: normal output operation	
W01	**-**	**-**	**-**	reset processor	software reset. value has no effect	
W02	-	-	-	load default parameters	load default values for all parameters	
W03	*00*	*00*	*01*	*reserved for future use*	*1: power saving and output disable.*	
W04	-	-	-	dump EEPROM content	get all permanent parameters	
W0B	-	-	-	enter bootloader	switches to bootloader on serial debug port	

Param.	default	min	max	Function	Description	R
Class L	LOOP			**Continuous Output**	Streaming comma separated results	
L00	-	00	01	Peak positions, Peak values	SpeedFW, SpeedBW, MagFW; MagBW<CR> (DECIMAL) Start:$L00 or $L0001; Stop: $L0000 or other parameter	
Class D	DEBUG			**Debug stream**	Control serial data stream loop **at debug interface**	
D00	-	00	02	Cyclic FFT on DEBUG int.	1: 2 ch. (FFT + Threshold); 2: 4 ch: additional I and Q	
D00	-	11	12	One shot FFT on DEBUG int.	11: 2 ch. (FFT + Threshold); 12: 4 ch: additional I and Q	

Table 8: 8 Bit parameters overview

8.3.2 16 Bit Array Parameters

Purpose: Values indirectly accessed by simple 8 bit parameters.

These parameters represent arrays that are addressed by 8Bit parameters or by signal processing. Values may be adapted and are application specific.

All values are in hexadecimal notation!

Param.	default	min	max	Function	Description	R
Class X	(EEPROM)			**Array parameters**	16bit hexadecimal table values for indirect parameters	
X00...X09	*)	0000	FFFF	Output hold time	hold time table in 100ms, addressed by parameter A01	x
X10....X19	*)	0000	00FF	Trigger level	sensitivity table, addressed by parameter A02	x
X20...X27	0	0	007F	Narrow band FFT filter	masks out single FFT bins from trigger criteria	x

*) see tables below

Table 9: Array parameter Xnn overview

Output Hold Time Table

Values from this tables are addressed by parameter A01 (Hold Time).

Default values:

Param A01 value	0	1	2	3	4	5	6	7	8	9
X00...X09 HEX	0002	0005	000A	0014	0032	0064	00C8	0190	0320	0640
→ Seconds	0.2	0.5	1	2	5	10	20	40	80	160

Table 10: Array parameter X0n hold time

Trigger Level Table (Sensitivity)

Values from this tables are addressed by parameter A02 (Sensitivity)

Default Values:

Param A02 value	0	1	2	3	4	5	6	7	8	9
X10...X19 HEX	00F0	00C8	00A0	008C	0078	0064	003C	0028	0014	0000
Decimal	240	200	160	140	120	100	60	40	20	0

Table 11: Array Parameter X1n trigger level

FFT Filter

Up to 8 different, individual frequencies may be filtered by setting values according to the FFT frequency resolution (called *df*).
Filtered frequency = Parameter X * *df;*

FFT frequency resolution:
Frequency resolution *df* depends on sampling rate *fs* and on FFT size *FFT_N*.
FFT_N = 256 (for RSP1); *fs* = depends on parameter S03; *df = fs / FFT_N.*

Frequency resolution depend on setting of parameter S03:

Param S03 value	1	**2 (default)**	3	4	5	6	7	8	9
df frequency resolution [Hz]	5	**10**	15	20	25	30	35	40	44

Table 12: Frequency resolution depending on parameter S03

Example:
Parameter S03 = 2 -> sampling rate = 2*1280Hz = 2560Hz --> df = 2560Hz / 256 = 10Hz
We want also filter out very slow movements at 10Hz and
100Hz interference, typically caused by fluorescent lights in 50Hz mains.

Parameter	X20	X21	X22	X23	X24	X25	X26	X27
Value (HEX)	0001	000A	0	0	0	0	0	0
Filter frequency @ S03 = 2	10Hz	100Hz	--	--	--	--	--	--

Table 13: Array parameter X2n filter

8.4 Sampling Rate and Frequency Resolution

Parameter ***S03***	sample rate Hz	resolution Hz	max. frequency Hz	resolution km/h	max speed km/h	update time ms [1)]
01	1'280	5	640	0.11	14.5	200
02	2'560	10	1'280	0.23	29.1	100
03	3'840	15	1920	0.34	43.6	67
04	5'120	20	2"560	0.45	58.2	50
05	6'400	25	3'200	0.57	72.7	40
06	7'680	30	3'840	0.68	87.3	33
07	8'960	35	4'480	0.80	101.8	29
08	10'240	40	5'120	0.91	116.4	25
09	11'264	44	5'632	1.00	128.0	23
0A	22'530	88	11'265	2.00	256.0	12

Note 1): response time on host interface. Digital output depends also on params $A03 and $S02

Tabelle 14: Sampling rate - resolution - speed

9 Bootloader

RSP1 processor contains a fix programmed bootloader featuring:

- Storing, programming and copying parameter settings (EEPROM)
- RSP1 Firmware updating
- Access via the Serial Debug Interface

DO NOT TRY TO ERASE or program RSP1 processor with any different programming tool. Bootloader will be lost and RSP updating will no longer be possible.
RFbeam will not recover erased chips.

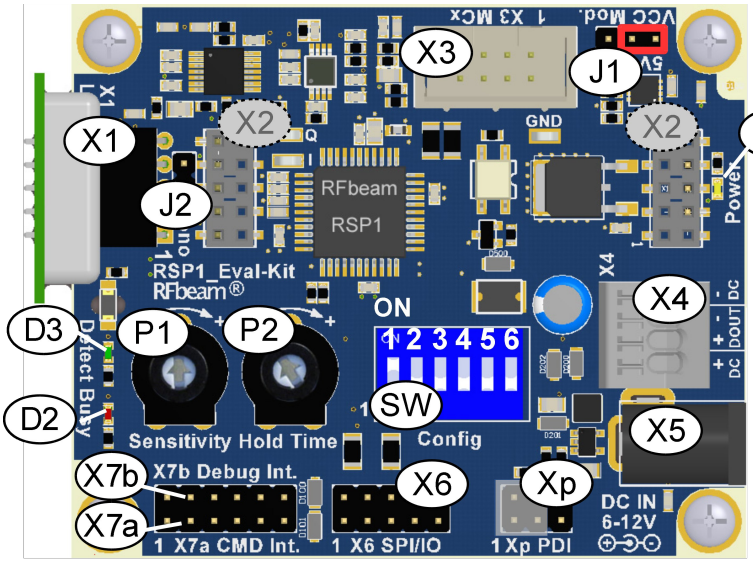
A PC program "RSP_Boot" comes with the RSP1_Eval-Kit.

10 Related Support Tools

For more details, please refer to the RSP_Eval-Kit User Manual.

10.1 RSP_Eval-Kit

This evaluation kit demonstrates applications of RSP1 with a large number of K-LCx sensor devices.
It is fully documented including schematics and PCB layout.



Indicators	
D1	Power LED
D2	Busy LED (start-up)
D3	Detection LED
Connectors	
X1	K-LCx sensor connector
X2	***Backside*** K-LCx connector
X3	K-MCx sensor connector
X4	Digital output connector
X5	DC Supply input 6 .. 12V
X6	Digital I/O (SPI in preparation)
X7a	Serial Command (**RSP_Terminal**)
X7b	Serial Debug (**RSP_Scope**)
Xp	Reserved / Reset
Settings	
P1	Sensitivity pot
P2	Hold time pot
SW	Mode switch
J1	Sensor supply volage
J2	Optional for mono sensor

Fig. 12: RSP1 Evaluation Kit

Evaluation kit contains the following software tools:

10.1.1 RSP_Terminal Software

This Windows software allows exploring and setting RSP1 parameters via the serial "Host command Interface".

10.1.2 RSP_Scope Software

This Windows software is a virtual oscilloscope for viewing internal FFT signals, thresholds, I/Q time domain signals.
It also allows setting parameters and exploring graphically their function.

10.1.3 RSP_Prog Software

This Windows software allows RSP parameter exchange with a PC.
It also includes an RSP1 chip software update utility.

11 Electrical Data

11.1 Power Supply

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
Digital supply voltage digital		Vcc	3.0	3.3	3.5	V
Analog supply voltage		AVcc	3.0	3.3	Vcc + 05.	V
Digital supply current		IVcc		12	15	mA
Analog supply current		AIVcc		3		mA

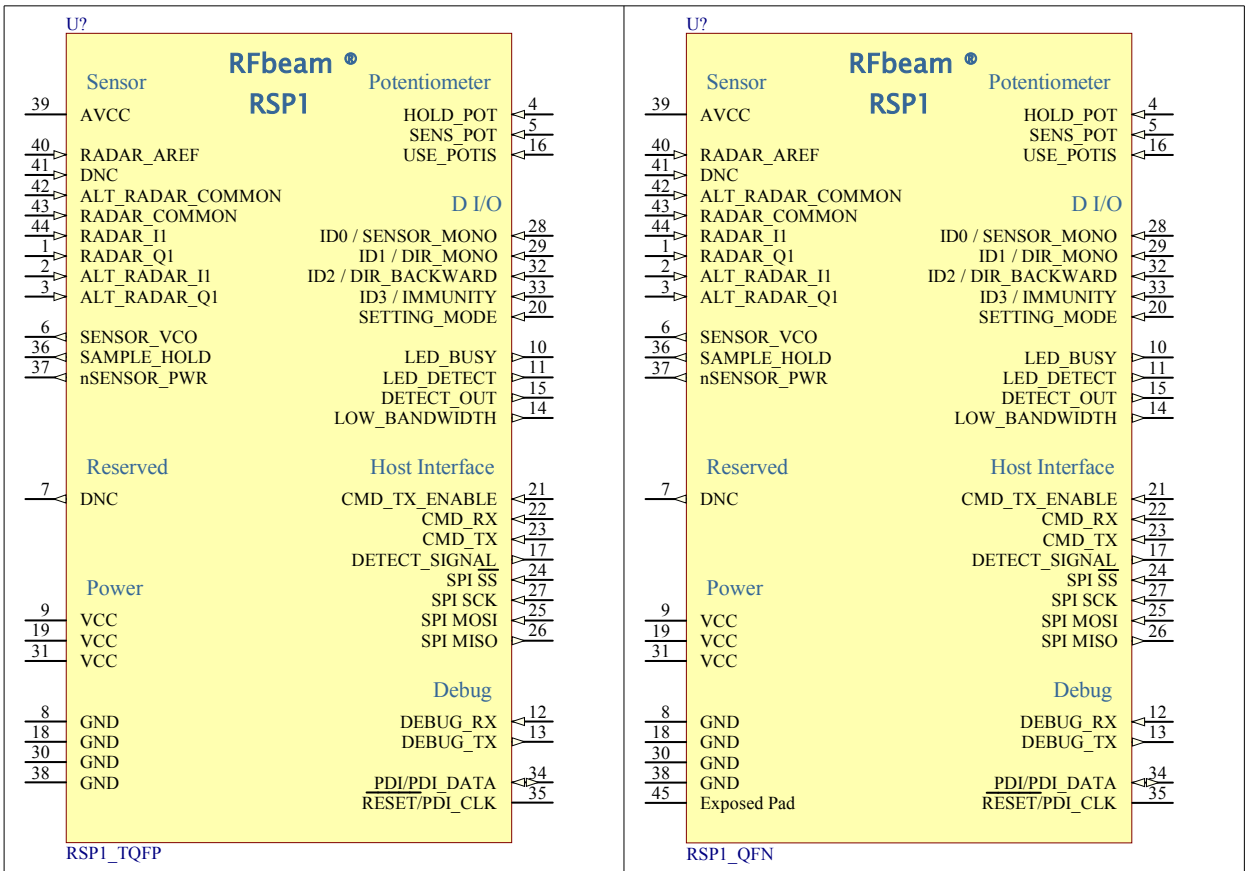
11.2 Analog I/O

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
ADC Resolution				12		bit
Sampling rate	adjustable by parameter S03		1.280		22.528	kHz
Reference input voltage range			1.6	1.65	1.7	V
Reference input resistance			10			MΩ
Radar Input type			--	differential	--	--
Radar input sensitivity	Gain = 1, V_{REF} = 1.65V	A_1		860		µV/bit
Radar input sensitivity	Gain = 16, V_{REF} = 1.65V	A_{16}		54		µV/bit
Radar Input impedance				4		kΩ
Radar Input capacitance					10	pF
Potentiometer input impedance				100k		kΩ
Potentiometer input range	V_{REF} = 1.65V		0		V_{REF}	V

11.3 Digital I/O

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
Input voltage high		V_{IH}	2		V_{CC} + 0.3V	V
Input voltage low		V_{IL}	-0.3		0.8	V
Input currents		$I_{IH,}$			140	µA
Output current		I_{OH}, I_{OL}	-20		20	mA
Output voltage high	I_{OH} = -8mA	V_{OH}	2.6	2.9		V
Output voltage low	I_{OL} = 10mA	V_{OL}		0.4	0.76	V

12 Pin Configuration



Standard RSP1 package: 44 pin TQFP	On request: 45 pin QFN package

Fig. 13: RSP1 Pin Configuration: left TQFP case, right QFN case

13 Sample Schematics

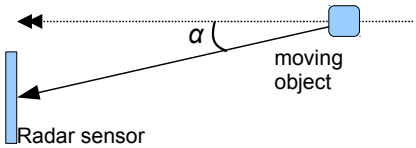
For complete schematics, please refer to the RSP1_Eval-Kit user manual.

13.1 Amplifiers

13.1.1 Sensor Outputs

A moving object in range of a Radar sensor (often called “transceiver “) generates a low frequency output signal. Frequency depends on the object speed. Amplitude depends on distance, reflectivity and size of the object. Doppler frequency f_d is proportional to the object speed v:

$$f_d = v \cdot \frac{44\text{Hz}}{km/h} \cdot \cos\alpha$$ or $$f_d = v \cdot \frac{158\text{Hz}}{m/s} \cdot \cos\alpha$$ with



Note that the angle of the moving object reduces Doppler frequency.

Radar sensor signals have low frequency outputs called 'IF' outputs.
Most sensors of the K-LCx family do not have an integrated amplifier. This makes these devices universal and low cost. Different applications need different amplification and frequency response.
Sensor output amplitude can range from less than 100nV to some mV .

13.1.2 Amplifier Structures

The following example schematics show 2 channel (I/Q) solutions with one- and two stage amplifiers.
Dual channel configurations need I/Q (sometimes called "stereo" sensors) like K-LC2, K-LC5, K-LC6 etc.

Dual channel configurations are state-of-the-art solutions with much better noise and interference suppression than single channel solutions. Furthermore, dual channel allows distinguishing approaching and receding objects.
Please refer also to Table 4: Useful signal level conversions.

Single channel solutions need less components and can be used with low cost sensors like K-LC1 or K-LC3.

If only 1 channel is required, only amp of channel 'I' is is needed, but RSP1 inputs 'RADAR_I1' and 'RADAR_Q1' must be connected together.

RSP1 provides an internal programmable gain amplifier with gains from 1 to 32 (0dB to 30dB).
Gain is set by parameter 'S09'. Default setting is 32.

$$A_{total} = A_{intern} \cdot A_{extern}$$ - > in our examples

$$A_{total} = 16 \cdot 500 = 8'000 \text{ or } 24\text{dB} + 54\text{dB} = 78\text{dB}$$

Maximum detection range is a function of the signal/noise (S/N) ratio at the RSP1 input.
Higher gain does not automatically mean higher detection range.
For more details on optimal amplification refer to the RSP1_Eval-Kit manual.

Dual amp stage structures allow higher external gains, higher bandwidth and lower gain.
If high speed detection at maximum range is required, dual amp stage is the right choice.

13.1.3 Single Amp, 2 Channels

Example for speed ranges from 0.1km/h up to 180km/h. This configuration needs the RSP1 internal gain stage with A = 16 (24dB)

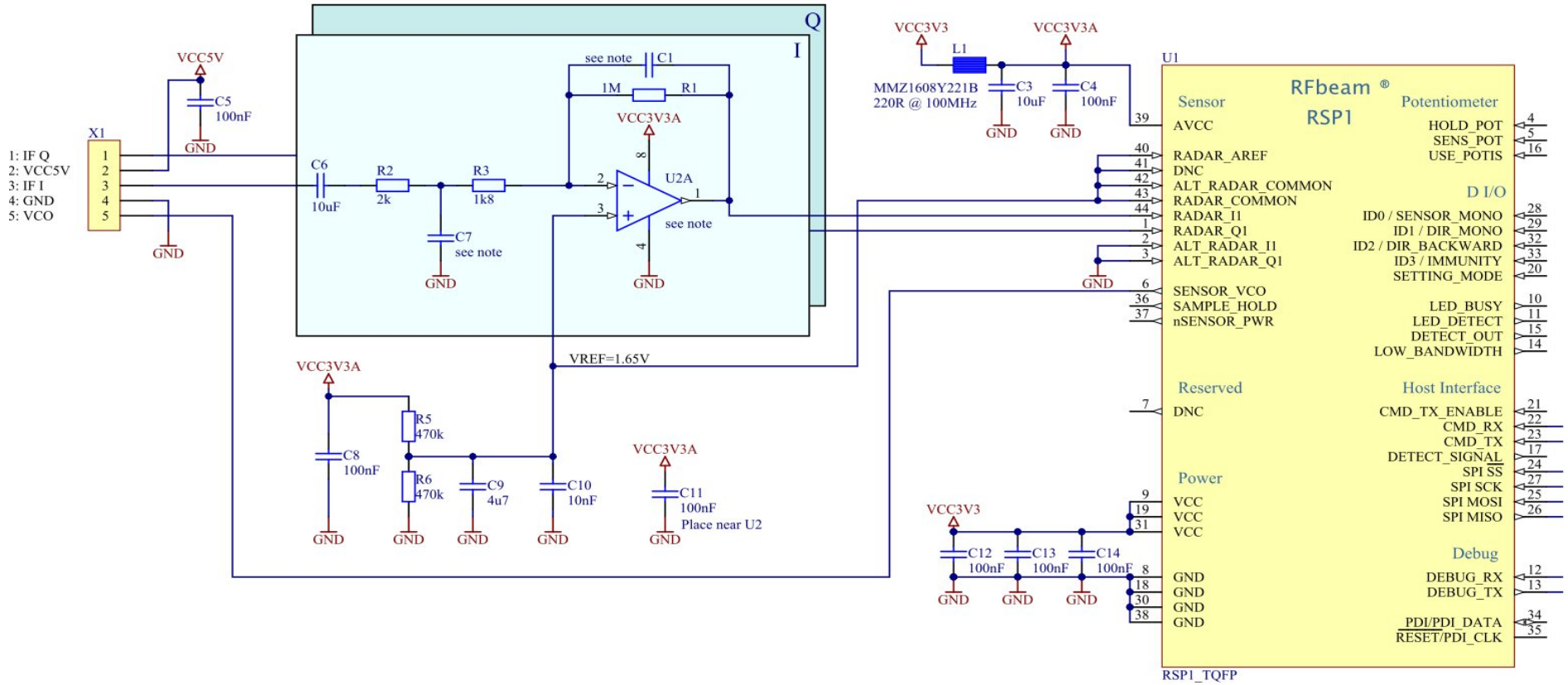


Fig. 14: Single Amp example for K-LCx sensors. Channel Q circuit is equivalent to channel I

Bandwidth (-3dB)	C1 *)	C7 *)	Op-Amp Type	Amp Gain
5Hz … 1kHz	15nF	120nF	LMV772	54dB (A = 500)
5Hz … 8kHz	15pF	15nF	LMP7716	54dB (A = 500)

*) For Q channel, same capacitor values

13.1.4 Dual Amp, 2 Channels

Example for speed ranges from 0.1km/h up to 250km/h. This configuration results in better S/N ratio and higher bandwidth than Single Amp solution

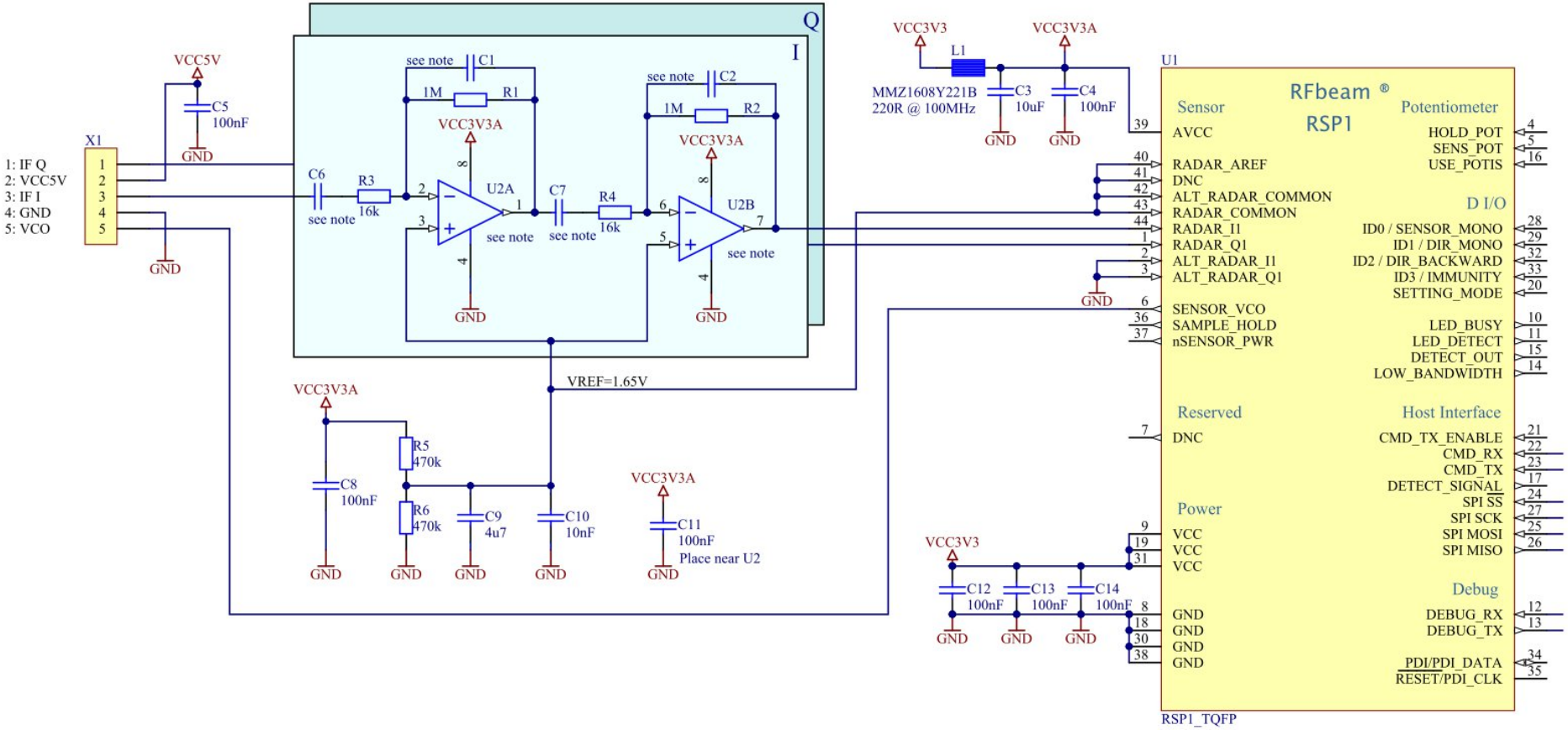


Fig. 15: Dual Amp example for K-LCx sensors. Channel Q circuit is equivalent to channel I.

Bandwidth	Speed range	C6, C7	C1, C2	R1, R2	Op-Amp	Amp Gain	Typical Application
5Hz … 500Hz	3cm/s 3m/s	2.2uF	15nF	120nF	LMV774	72dB (A = 15'800)	Person detection
400Hz … 12kHz	0.9 .. 270 km/h	33nF	10pF	15nF	LMP7716	72dB (A = 15'800)	Car speed or detection

For Q channel, same component values apply

13.2 Control Input Output

Please note: digital I/O are all 3.3V types.

13.2.1 Peripheral IO

All inputs are tied by a pull down resistor to ground.
All outputs switch to Vcc 3.3V.

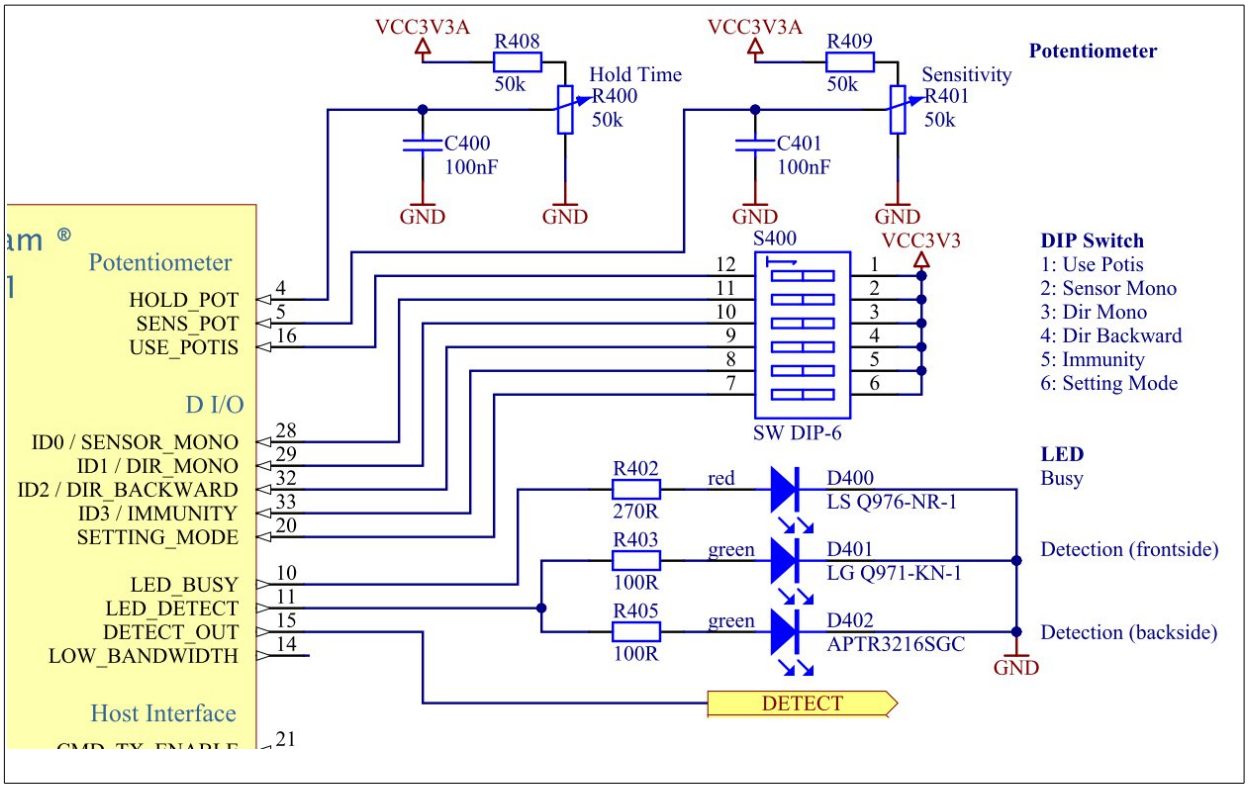


Fig. 16: Stand alone configuration, control elements

Isolated output is preferable in order to prevent ground loops and noise injection.

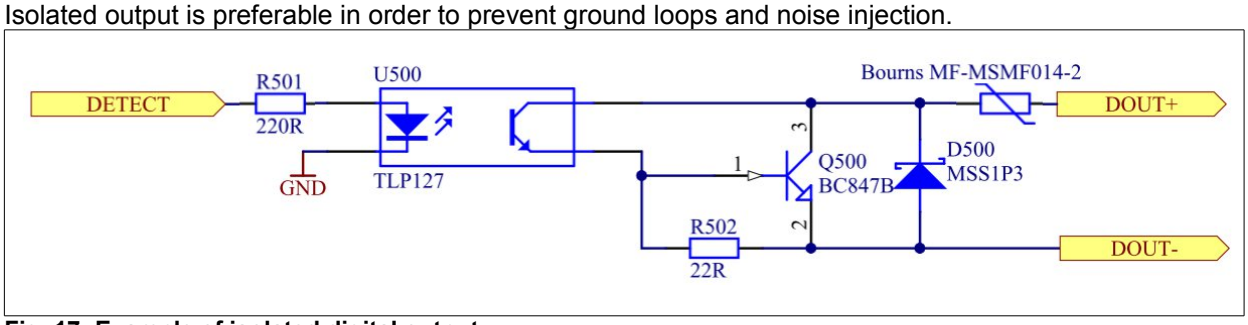


Fig. 17: Example of isolated digital output

14 Ordering Information

RSP1 processor in 44-pin TQFP case	RSP1-TQFP
RSP1 processor in 45-Pin QFN case	RSP1-QFN (on request for high volume production)
RSP1 evaluation Kit	RSP1_Eval-Kit

15 Revision History

Version 0.1	Mai 10, 2014	Preliminary release
Version 0.2	August 13, 2014	Preliminary release 2
Version 0.3	Sept 18, 2014	Preliminary release 3
Version 0.4	Nov 04, 2014	Preliminary release 4, valid from software version V1.7

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